REDESIGNING THE REPAIR PROCESS FLOW AT THALES HENGELO

THALES

UNIVERSITY OF TWENTE.

RUBEN WIENK

JULY 7, 2022

Master Thesis:

Redesigning the repair process flow at Thales Hengelo

Author

R.J. Wienk (Ruben)
University of Twente

Supervisors University of Twente

Dr. L.O. Meertens

Prof. Dr. M.E. Iacob

Supervisors Thales Naval Netherlands

Ir. J.F.M. van den Bosch
Product Manager Services

Ir. S.J.H. Huijink
Service Designer

GLOSSARY OF TERMS

- **TNNL (Thales Naval NL)** is a business unit of Thales. TNNL develops, manufactures and integrates naval mission and radar solutions for the defense market.

- **IST situation** is a term used to refer to the current state of the repair process flow.
- **SOLL situation** is a term used to refer to the desired state of the repair process flow.

Technical definitions:

- **RMA (Return Merchandise Authorization)** is a part of the process of returning a product to its supplier, for instance for repair. When the supplier approves a repair request, a RMA number is provided. Then the customer can return the product with the corresponding RMA number.

- **Indenture level of systems:** TNNL systems consist of multiple assemblies with different levels of detail. For repairs, customers mostly sent parts on LRU or SRU level to TNNL. Indenture levels that are mentioned in this research are:

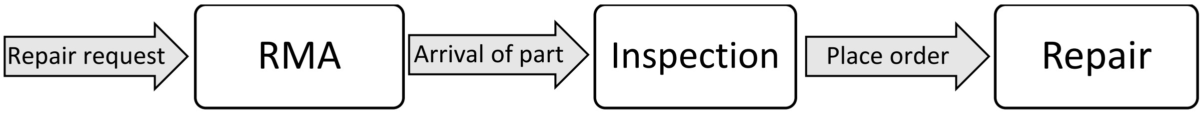
  1st. Line replaceable unit (LRU): a module of a system that can be replaced within a short time on board.

    2nd. Shop replaceable unit (SRU): is a modular part of the LRU that is designed to be removed and repair or replaced at the shop.

      3rd. Components are parts of the SRU that are repaired or replaced by the original equipment manufacturer, which is TNNL or a supplier of TNNL.

MANAGEMENT SUMMARY

The *Service & life cycle policies* department of TNNL is working on improving and redesigning their repair service to increase the customer satisfaction. This research follows a design methodology to provide a solution design to support their improvement project. With the goal to design and map an improved repair process flow, which enables structural information logistics and creates less uncertainty in the repair process. In short the inhouse repair process currently comprises three phases: RMA, Quotation and Repair. In the RMA phase, a customer submits a repair request, which is evaluated by TNNL. If the repair request is approved, an RMA number is provided to the customer. After the part is send by the customer and arrives at TNNL, technical inspection is performed to determine the required repair activities and component replacements, on which the quotation for the repair is based. When the customer accepts this quotation and places a repair order, repair activities can start.



In a customer survey, it came forward that the low customer satisfaction on the repair service was caused by two problems: a lack of transparency on the repair status, and long, unreliable lead times. In the analysis of the repair process flow, it came forward that the information logistics in the process is ad hoc and not standardized. Also the work process is inefficient due to a lack of planning, job routing and poor or ambiguous communication. As a result, little transparency is provided to the customer about the repair status of their part and the lead times are generally long and unreliable. Leading to low customer satisfaction on the repair service. All identified problems can be led back to the lack of standardization in the repair process flow. A formalization of the repair process steps is needed to define responsibilities and form a foundation for the structural process flow of all repairs. Also contributing to the standardization of information logistics in the process.

In the theoretical framework, literature in the field of customers satisfaction and supply chain collaboration is used to define how interaction can help with keeping the customer satisfied and engaged during the repair service. Then literature on information logistics and process design is collected to retrieve best practices of process designs and to analyze how TNNL can work towards a more standardized and rationalized repair process flow, with the aim to improve the process efficiency and the internal information structure, allowing more transparency to the customer.

Designed model and validation

After mapping and analyzing the current repair process, by conducting interviews with the involved departments and literature, I came to the conclusion that inhouse repairs should be split in distinct process flows: Repair by replacement and Complex repairs.

In the Repair by replacement stream, components are directly replaced during test inspection. In this process flow, TNNL should be able to give a quotation before inspection (and direct repair) to avoid the risk of quotation rejection afterwards. This results in a simpler process with less uncertainty and a shorter lead time, since components can be replaced during testing and no quotation is required in between.

The Complex repair stream follows roughly the same phases as the current process. The focus here is mainly on standardizing the information logistics and making the contact with customers more proactive.

The designed model is validated by expert opinions to evaluate if the implementation of the process flow of the solution design solves the identified problems. The IST and SOLL situation are compared and it can be validated if the new process flow improves the performance of the repair service.

Conclusion and recommendations

From the model validation, it can be concluded that an implementation of the designed model concepts improves the performance of the repair service.

By forming a standard internal information structure in the process, the external communication to customers can be improved and standardized. Enabling TNNL to communicate more frequent and proactive to the customer, increasing customer's transparency on the repair process.

By creating a separate repair stream for replacements, shorter and more reliable lead times can be accomplished for these products. The process requires less work hours and administration, because inspection and repair activities are performed at once and are easier to execute. Therefore, more resources and work hours are available for the Repair shop and engineers to focus on the information logistics of the complex repair stream, where opportunities lie to give more operational transparency and increase customer involvement in the process.

Furthermore the designed model can contribute to the structure and uniformity of the process flow, to increase the efficiency of the work process. Especially when capacity planning and job routing is realized in the work cells. Improving the performance on the repair lead time and on time delivery.

In this way, the designed model contributes to resolving both underlying causes of low customer satisfaction: it increases the transparency to the customer, and it supports achieving shorter and more reliable lead times.

Table of Contents

Table of Figures

1. RESEARCH METHODOLOGY

1.1 Introduction

The Thales Group is a French multinational that designs, develops and manufactures electrical systems for the global market. The company is present in 68 countries, has over 81.000 employees and a total sales of 16,2 billion euros in 2021. At this moment, Thales Group has five business segments:

- Digital Identity and Security
- Defense and Security
- Aerospace
- Space
- Ground Transportation

The Dutch division of the Thales Group, Thales Nederland, is mainly engaged in the Defense and Security segment. This thesis takes place in that segment, at Thales Hengelo, which is the main location of Thales' business unit Naval NL. Thales Naval NL (TNNL) develops, manufactures and integrates naval mission and radar solutions for the defense market. Their naval strategy is to be a total solutions provider, so they provide a complete service package with guaranteed performance and availability of the systems and equipment throughout the life cycle. These services include the supply of spare parts and the repair of failed parts. The market that TNNL operates is characterized by low volumes, high diversity, long life cycles and military standards for support and services.

Service designers of the *Service & life cycle policies* department of TNNL are working on improving and redesigning the repair service to increase the customer satisfaction. They are undertaking internal analysis in the organization, while this research follows the academic approach to support their decision regarding the process flow design of the repair service. In the process flow, the physical, communication and information flows between internal departments and external parties are considered.

In short, the repair process currently comprises three phases: RMA (Return Merchandise Authorization), Inspection, and Repair. In the RMA phase, a customer submits a repair request that is evaluated by TNNL. If the repair request is approved, an RMA number is provided to the customer. After the part is send by the customer and arrives at TNNL, technical inspection is performed to determine the required repair activities and component replacements, on which the quotation for the repair is based. When the customer accepts this quotation and places a repair order, repair activities can start.

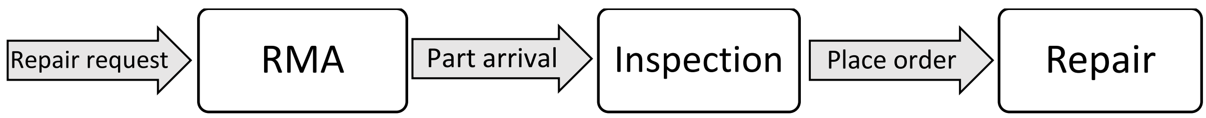


Figure 1: Simplified depiction of the current repair process in phases.

1.2 Problem context and core problem

In this chapter the research problem will be defined by identifying problems in the current repair process, starting from the action problem: low customer satisfaction on the repair service. From this, the problem cluster of Figure 2 is derived based on the method of Heerkens & Winden (2012). In this problem cluster, the cause and effect relations between observed problems are illustrated, so that the causes of the action problem are derived and a core problem can be pointed out. The problems are derived from meetings with my supervisors and interviews with the involved departments, see Appendix A for a detailed description of the interviews. The core problem can be derived by going back in the problem cluster to find a problem that does not have a direct cause. The action problem is an observed discrepancy between norm and reality (Heerkens & Winden, 2012). In this context, the low customer satisfaction is the action problem. A couple of years ago, a customer satisfaction survey on the services of TNNL was held and the results were not generally positive. With regard to the repair service, customers were unsatisfied with the long and unreliable lead times, and the lack of transparency on the state of the repair during the process.

In the evaluation of the current repair process, some areas of concern arise in the internal communication between the involved departments in the repair service. The departments are mostly operating with their own viewpoints and priorities in mind, without regarding the needs of other process participants. This phenomena is called an 'eilandjescultuur' in Dutch, which includes a lack of knowledge about the work processes, planning and information needs in other departments. Because of this, there is a lack of communication and information sharing through the organization. These identified problems can be grouped as the absence of standards in information logistics.[1]

This lack of information logistics affects the external communication to the customer. Throughout the process, only a few updates are given to the customer about the repair status, while the process can span over a year. With the result that customers frequently contact the Customer Contact Center (CCC) of TNNL about the status of their repair. The CCC employees sometimes have to communicate across multiple departments to obtain the required information, which is a reactive, tedious and inefficient work process for all involved departments.

Not only the internal communication is an example of an inefficient work process, also in the repair operation is a lot of room for improvement. First, there is no structural planning of test and repair activities. When a job gets assigned to a work cell of engineers, the repair gets piled up at the work cell and it is performed ad hoc without a structural logic. Second, there is no job routing for the repairs, so it cannot be easily retrieved where the part is and what the status is. Third, it occurs that repair activities have been finished before the customer has accepted the quotation and placed an order, with the risk that the customer can choose to decline the repair quotation and the repaired part is sent back without incurring repair costs. These issues lead to longer lead times with uncertainty. Since jobs are not planned ahead, the lead times are mostly estimations without a quantitative foundation.

[1] Information logistics definition: Klein (1993) stated that the concept of information logistics links the functions of business logistics and information management, by the control and coordination of intra- and inter-organizational information flows. In addition, it concerns the documentation and storage of process information to facilitate this information infrastructure (Dinter & Winter, 2009).

These problems can be led back to the repair process flow. There are no procedures or standard repair process flows written down or established to get everyone on the same page. A formalization of the repair process steps is needed to define responsibilities and form a foundation for the structural process flow of all repairs. Also contributing to the standardization of information logistics during the process.

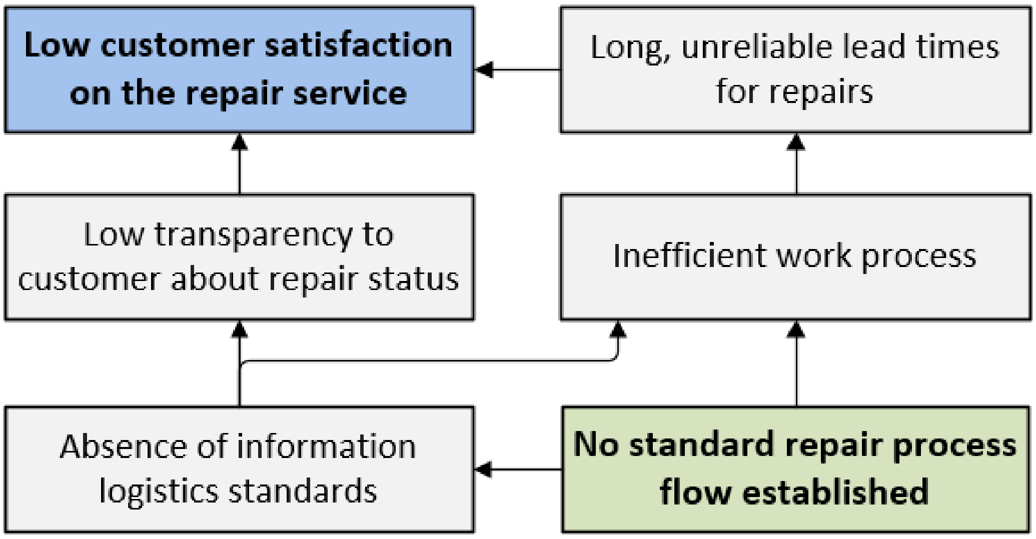


Figure 2: Problem cluster (the action problem in blue, the core problem in green).

1.3 Research Questions

Based on the identified core problem from the problem context, the research question is:

> ***What should the design of the repair service be to improve customer satisfaction?***

To answer the main research question, it is split in sub questions:

- ***Which business process design methodology is applicable to the design of the repair service of TNNL?***
  This sub question will be answered in Chapter 1.4, concerning the research methodology.

- ***What are the customers' expectations of the communication with TNNL during the repair service?***
  This is the starting point for the research since the repair process will be redesigned to facilitate and meet customers' expectations during the service. This question will be answered using literature on operational transparency, perceived waiting time of customers, and supply chain collaboration. And by conducting interviews with employees of the CCC to define customers' expectations.

- ***How should the information logistics in the repair process be shaped to meet customers' expectations?***

After defining the customers' expectations, an internal information structure should be shaped that facilitates transparency to the customer and proactive communication. This question will be answered using literature on information logistics and process design. And by conducting interviews with employees of the involved departments in the repair process to investigate the missing communication between departments that hinders them in their providing transparency.

- ***How should the repair process flow be designed to support an efficient work process with standard information logistics?***
  In order to establish an efficient work process in and between the involved departments, the process flow must be designed in a way to facilitate this. By conducting interviews with employees of the involved departments in the repair process, it is determined what issues they encounter during the process that lead to inefficiency. The problems encountered in the interview will be answered using literature on process design to shape a standardized process that facilitates the information logistics and resolves issues.

1.4 Research methodology

The approach to tackle the core problem is to design the process flow of the repair service to create more transparency to the customer, and to evaluate process steps that are causing unnecessary complexity and uncertainty in the process. Such a problem can be defined as a design problem. A design problem is a problem to (re)design an artifact so that it better contributes to the achievement of some goal (Wieringa, 2014). In this case, the artifact is the repair process flow and the goal is to improve the customer satisfaction by offering more transparency. Peffers et al. (2007), laid the foundation for design science research methodology (DSRM) by defining a stepwise approach for design problems, which forms the basis for many variants of DSRM. The problem approach used in this thesis will be based on the Design Science Methodology book of Wieringa (2014). The main alteration to the DSRM of Peffers et al. (2007) is that the book works with iterative cycles instead of a stepwise approach.

In the book of Wieringa, a design science framework is composed to support research. An application of this framework on this problem context can be seen in Figure 3. In this framework, design science is split into two elements: design and investigation. The interaction between these two elements, the literature in the knowledge context and the stakeholders in the social context is illustrated. In Chapter 1.5, it is discussed in more detail how the framework is applied in this research.

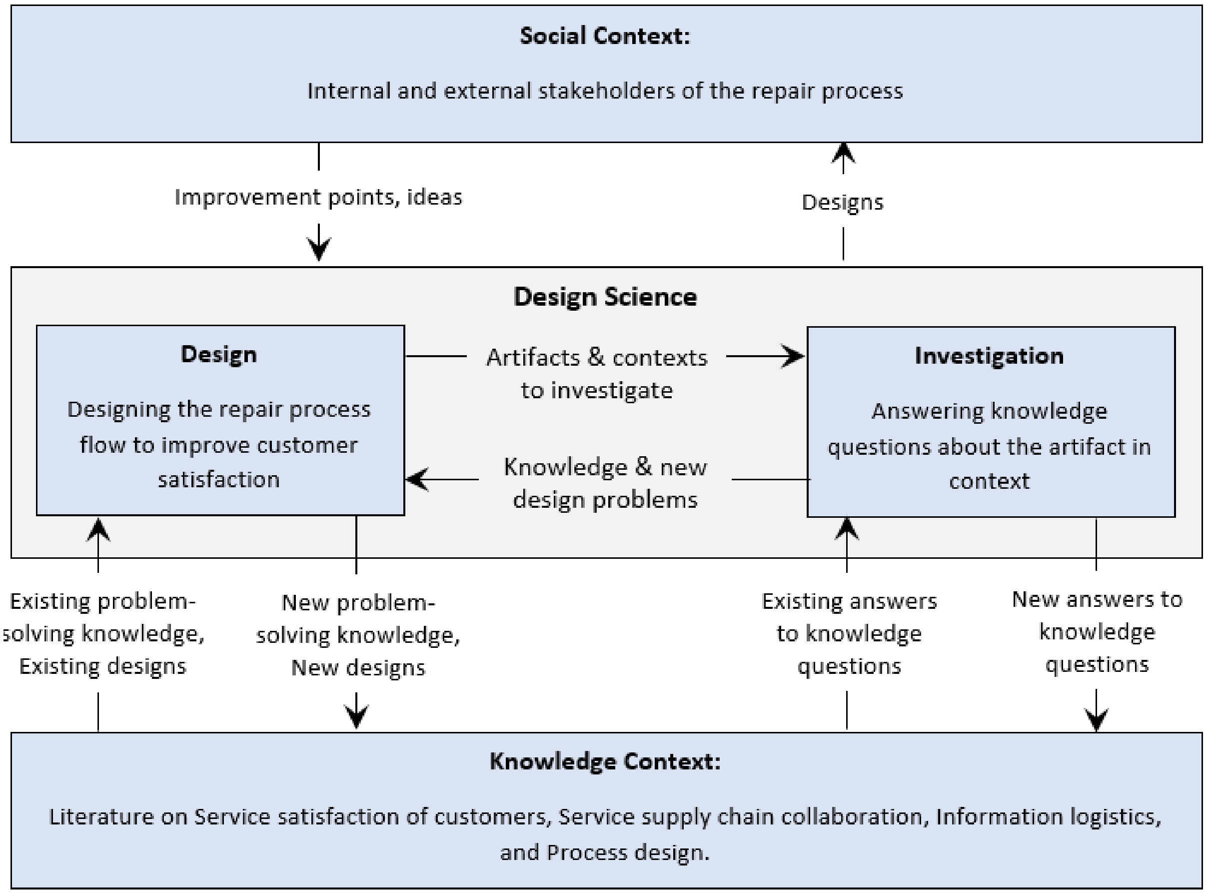


Figure 3: Design science framework of Wieringa.

In the design element, design problems are treated by following the design cycle that consists of three tasks:

- Problem investigation: What phenomena must be improved? Why?
- Treatment design: Design an improved repair process flow that could treat the problem.
- Treatment validation: Would this process flow design treat the problem?

These tasks are on purpose not defined as steps, because in the design cycle, researchers could iterate over these tasks multiple times. However this research does one iteration of the design cycle.

In the investigation element, knowledge questions are answered by following the empirical cycle, which is similar to the research cycle from Heerkens & Winden (2012). It is a generic cycle, so not all tasks are necessary depending on the type of research. For this research the following tasks are defined:

- Research problem analysis: framing of the research problem, see Chapter 1.2.
- Research design: research setup, what is the strategy to solve the knowledge question? See knowledge context paragraph at Chapter 1.5.
- Research execution: information collection according to the research design, from literature as well as from interviews with stakeholders.
- Data analysis: analysis and conclusions on the collected sources for follow-up research and designs.

1.5 Research design

A design science project starts from the knowledge context to collect prior knowledge, which is called the theoretical framework of the research project (Wieringa, 2014). This will be treated in the literature study of Chapter 2, where theories from academic papers are gathered and analyzed to obtain knowledge for the design element and the investigation element, as demonstrated in the framework of Figure 3. Also in Appendix B, prior knowledge is gathered about Integrated Product Support, the service standard of the naval industry, to analyze its influence on TNNL's repair service.

From the **knowledge context**, theories are gathered to contribute to the design and investigation elements. For the design element, existing problem-solving knowledge and work processes are collected to retrieve best practices from other companies in service supply chains. This knowledge covers standardization and rationalization for the design of the process flow to solve the identified problems in the repair service. It should be considered if the practices from the literature are constrained and how they should be applied to the repair process flow of TNNL. For the investigation element, literature is used to answer the knowledge questions of Chapter 1.3 and to support process design. Literature in the fields of customers satisfaction, perceived waiting times, and supply chain collaboration is used to define how communication can improve customer satisfaction and involvement. With help from the interviews, it is then defined how the internal communication should be shaped in the repair service to facilitate this, and how to improve data availability for all stakeholders.

In the **social context**, semi-structured interviews are performed with internal stakeholders of the repair process to get an overview of the current operations and the involved issues, to identify problems in the process flow and information logistics of the repair service. The interview process starts from CCC employees, which are in direct contact with customers, to define what the customer expects in the communication with TNNL and what information is missing to give more transparency. From here, the interview process goes to the departments involved in the operations of the repair service to get an overview of the operational flow and information structure there. In this way, the current information logistics are evaluated and problems are identified that are causing unnecessary complexity and uncertainty in the process.

Problem investigation. The theory from the literature study and the input from stakeholders is then applied to the current repair service, the so called IST situation, where the existing process flow is depicted with a business process model. A business process model of a service allows a company to explore all the issues inherent in executing and managing a service, by identifying all involved process steps and isolating fail points in the process (Shostack, 1984).

Treatment design. By evaluating the model, using the best practices from the literature and the interviews, points for improvement are identified that are translated into requirements for the design of an improved repair process flow model, the SOLL situation.

Treatment validation. To validate the design of the repair process flow, expert opinions are required, because this research does not span over the actual implementation of an improved process flow. Wieringa (2014) describes this as follows: *"The design of an artifact is submitted to a panel of experts, who imagine how such an artifact will interact with problem contexts imagined by them and then predict what effects they think this would have."*
From the problem identification of the current repair process, performance measures are derived.

Based on the identified problems, the proposed alterations and requirements for the solution design of the improved process flow, experts will evaluate the designed model and which effect the alterations have on performance measures in comparison with the current situation. Also participants can share their own consideration on the model to identify attention points. In this way, the models can be compared and it can be validated if the process flow of the repair service is improved.

From the model validation, conclusions are drawn and recommendations are given that can help the Service & life cycle policies department with shaping an improved process of the repair service. In the recommendations, a distinction is made between issues that can be solved in the short term and in the long term.

1.6 Stakeholder analysis

Following the design science methodology of Wieringa (2014), a stakeholder of the problem is a person or group of persons affected by treating the problem. So for the redesign of the repair process flow, stakeholders are internal departments, also called process participants, and external stakeholders: the customers and suppliers. See for more detailed information on the internal process participants the interviews of Appendix A. In Figure 4 below, the stakeholders and their contribution to the process is illustrated.

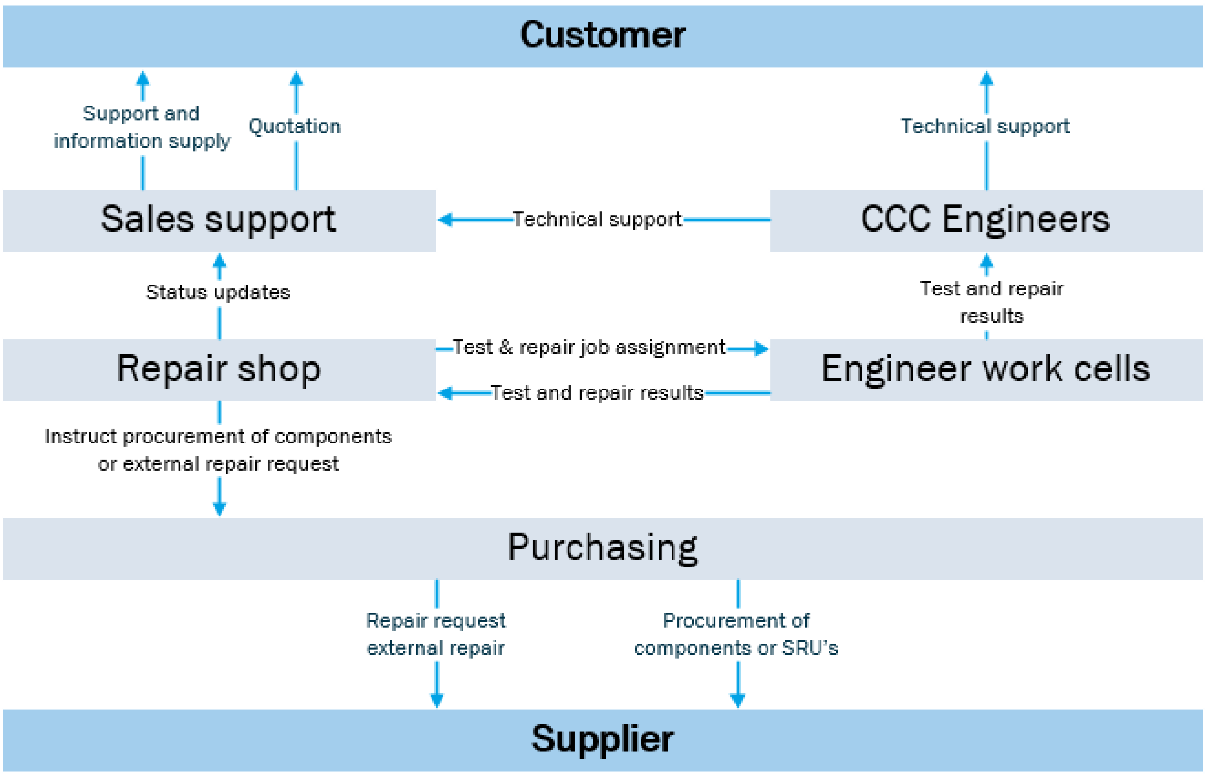


Figure 4: Stakeholder relationship diagram.

1.6.1 Internal stakeholders

Customer Contact Center:

When a client comes in contact with TNNL, the Service Desk process offers first line support and channels all incoming requests. The service desk is a service, the CCC employees are the workers that execute the service desk tasks. In short, the service desk process includes:

1. Assignment of responsible CCC employee and the registration of a request, with checkboxes like existing client, type of service etc.
2. Confirmation to customer that request will be processed.
3. Status updates on the state of the service, desirably every two weeks.
4. After service completion, feedback is asked to the customer on the received service.

The objective of the service desk is to provide a single, central point of contact between TNNL and its customers, and ensures that the customer receives appropriate support in a timely manner on their requests.

The stakeholders of the service desk are CCC employees and the responsible product managers. The CCC employees can be divided in Sales support employees and CCC engineers:

- **Sales support** employees are the first point of contact for the customer and execute the service desk tasks described above. For the repair service, customers contact them for repair requests, purchase orders for repairs and updates on the repair status throughout the process. They also provide the required shipment documents for inbound and outbound parts, and the quotation for a repair to the customer.
- **CCC engineers** (CCCE) provide technical support to Sales support and to customers. For the repair service, CCCE is mainly involved in the early phases. When Sales support receives a repair request, CCCE technically assesses it to decide if the best choice for the unit is repair, and if so they provide an RMA to Sales support. After arrival of the part at TNNL, technical inspection starts, where tests are carried out by engineers at the production facility. Based on analysis of the test results, CCCE subsequently collaborates with the Repair shop to compile the FAR (Failure Analysis Report).

Other internal stakeholders:

- **Repair shop** employees do not carry out tests or repair jobs themselves but they are responsible for the logistic flow of the repairs through the facility. This concerns job routing, job assignment and planning during inspection and repair. They are also the first point of contact for Sales support if they require a status update for their customers.
- **Engineers** carry out tests, to analyze failures, and repair jobs. Afterwards they document the test results and job details. Engineers are split up in different work cells with their own expertise, like electrical engineers, etc. Repairs are only a small fraction of the work in the production facility, since the main focus is on manufacturing new systems to customers.
- The **Purchasing** department is in contact with the suppliers of TNNL that produce components or subsystems of TNNL's naval systems. In the repair process, the Purchasing department can get involved at three moments. First, they order new components if replacement is necessary and the component is not in stock. Second, they apply repair requests to the supplier for external repairs, which process look similar to that between the customer and the CCC. And third, for contacting the suppliers for status updates if they are instructed to do so by other departments.

1.6.2 External stakeholders

- **Customers** are governmental naval organizations and the owners of the systems. When a part has a failure, they apply a repair request. After the part is approved for repair, they can ship it to TNNL. In the inspection phase, TNNL analyzes the failure and draws up the quotation for repair. After which the customer can place a purchase order for the repair. Throughout the process, customers contact the CCC to retrieve status updates about their repairs. It is important that they have insight in when the part will be fixed and functioning again, so that they can plan their operations with radar equipment ahead. Their low satisfaction on the repair service is the action problem of this research making them crucial stakeholders.
- **Suppliers** are involved in the supply of required components when replacement is required and in cases where repairs are outsourced to the suppliers, these are called external repairs. During external repairs, TNNL sometimes asks for status updates to communicate with their customers. The Purchasing department of TNNL handles the contact with suppliers.

1.7 Research scope

As said TNNL does internal analysis in the organization to redesign the repair process, while this research follows the academic approach with an objective view from the outside to support their design decisions. Therefore this research will not analyze the internal data from information systems to quantitatively justify decisions and results, instead the decisions are justified by literature and follow from interviews. To validate the decisions, expert opinions are used from process participants. The research is restricted to the repair service of TNNL.

This research contributes to the redesign of the repair process in the broad sense by considering all process participants, focusing on the interaction between them. Therefore, it will not focus on the operational implementation of the designed process flow in detail for a specific department. For instance, a capacity planning is advised for the repair shop to reduce uncertainty and increase efficiency, but this research does not include how to establish it, merely some output requirements are considered.

The redesign of the repair process flow will not go into too much detail regarding external repairs at suppliers, because it is difficult to influence the work process and communication of the supplier. "TNNL cannot impose obligations to its suppliers, because it does not have contract agreements with suppliers. Also the repair stream from TNNL to suppliers is very erratic and of low importance for suppliers in terms of turnover, so TNNL cannot leverage or put many requirements on the service of the supplier" (Appendix A.5.2). For external repairs, TNNL plays the role of intermediate between the supplier and the customer with the goal to align the agreements with the supplier to the expectations of the customer regarding communication on the repair.

1.8 Scientific relevance

This research applies design methodology for a process flow design of a repair service that is characterized by low volume, high diversity and long life cycles. Because of the low volume and high diversity, the inspection and repair activities are difficult to automate, since it concerns unique or customized systems with an erratic demand for repair services. The long life cycles of TNNL's radar systems bring service provision challenges in terms of knowledge management and risk of component obsolescence for older systems. The required expertise, test equipment and components might not be available decades after delivery of the systems. In the literature about repair process flows, not much can be found about businesses with these complex characteristics. Therefore, general theory about customer's service satisfaction and process design must be adapted and applied to this case, adding to the limited literature in this field.

The design science approach and the resulting solution design for the repair process flow can be similar for the repair process flow of businesses with comparable characteristics, such as the repair and maintenance of complex machinery. Also the designed repair process flow and recommendations may be applicable to other facilities and business segments of the Thales Group, for instance for the business segments space and aerospace.

Furthermore the process flow design could form an example of process customization for different product groups. By using design methodology and rationalizing process steps by eliminating non value added activities, the design of a process flow that fits repair by replacement strategy is created.

2. KNOWLEDGE CONTEXT: THEORETICAL FRAMEWORK

2.1 Customer satisfaction on services

Wang et al. (2010) defines customer satisfaction on services as the customers' overall evaluation of the service experience, based on a comparison between prior expectation and perceived performance. This comparison is not only based on the quality of the repair, but also on the experience of customers during the process. The customer service experience is mostly influenced by the interaction quality with the supplier. To improve the interaction during the service, companies need to find ways to intensify information sharing with customers and expand customer participation and choice in the process (Hong & Kim, 2020).

Operational transparency can play a crucial role in achieving this. The article of Buell (2019) shows that when customers are shut off from a company's operation, they are less likely to appreciate the value being created. As a result, they are less satisfied, less willing to pay, less trusting, and less loyal to the company over time. The first step of bringing more operational transparency in a company is to think about where in the process opportunities lay to give status updates to customers with low effort. Consider what information concerning the repair process flow is already documented in the internal databases that would be appreciated by the customer. Furthermore, transparency works best when it is proactively provided and not pulled out of departments at the customer's request. Besides, transparency about status, customers want more involvement in decisions about their system, for instance if irregularities happen.

Besides the quality and transparency of the service, waiting time is a crucial part in customer satisfaction. Repairs at TNNL have lead times of multiple months or even a year, with much effort they are gradually decreasing the lead times over the last years. Besides redesigning the repair process to support this decrease, the focus of this project is also on decreasing the perceived waiting time of customers. The paper of Maister (1985), introduced propositions of perceived waiting time, thereafter research of Davis & Heineke (1994) and Jones & Peppiatt (1996) added to these propositions. These propositions are derived from a queuing system in a business to customer context, where the customer waits in a waiting room to receive service at a server. In the business to government context of TNNL, not all of these propositions are applicable. The relevant propositions for perceived waiting time of the repair service will be discussed below.

- ***Pre-process waiting times feel longer than in-process waiting times***. Initial waiting time before entering the service system is perceived longer than subsequent waits inside the system. Currently, there are three gateways in the repair process where an action of the customer is required beforehand: the RMA phase, the inspection phase, and the repair phase. After an action of the customer, the customer should be informed that they are in-process of the next service phase to reduce the perceived waiting time.
- ***Waiting times with uncertain duration seem longer than waiting times with certain duration***. Customers want to receive a lead time upfront of their repair to create certainty in their planning. When the lead time cannot be determined early in the process, updates or status reports at agreed intervals can be acceptable substitutes (Davis & Heineke, 1994).
- *Unexplained waiting times seem longer than justified, explained waiting times.* If a reason is given why there is a (long) waiting time, customers are less likely to be frustrated or

dissatisfied than if there is no explanation given for their delay (Davis & Heineke, 1994). A reason could be, for instance, that a certain resource is not available yet or a component is not in stock. The customers' perception of fairness is important here; it should be explained why that resource could not be planned or the components ordered beforehand.

- *For valuable services, customers are more willing to wait*. If the usefulness of the repair service can be explained and emphasized better, customers will accept the required time-investment and tolerate long lead times more.
- *New or infrequent users of the service experience waiting times longer than regular users.* It is key to check if the customer is familiar with the process, if not they should be thoroughly informed on the service process and the justification for the lead times.

2.2 Supply chain collaboration for services

In the role of TNNL as a total solutions provider, after sales services play a crucial role. Besides, the close contact with customers during the life cycles does not only reduces the distance between customer and supplier; it also helps with recognizing changes in customer requirements and technological development potentials in time (Meier & Massberg, 2004).

In a case study of Brax (2005), challenges where identified for manufacturers that provide services. It came forward that the traditional transaction-focused projects of manufacturers do not support service business and that services require more effective information management. This means that organizing work as projects is not suitable for services, because customers need support continuously. Instead an integrative information system and information management practices are key in developing a close service relationship and intensify supply chain collaboration.

Supply chain collaboration (SCC) concerns the inter-organizational processes between members of a supply chain, with the goal to create a synchronized and integrated supply chain with increased responsiveness and performance to satisfy customers (Ho, Kumar, & Shiwakoti, 2019).

To evaluate the degree of SCC at a company, maturity models are a useful tool. It consists of a list of maturity levels to characterize the processes of a company. Maturity is a measure to systematically assess the performance level of the business processes (Harrington, 2006). The higher the maturity level, the higher the quality of the processes. Therefore, a maturity model is considered as a development path or an improvement tool for organizations (Looy, Backer, & Poels, 2014).

Ho, Kumar, & Shiwakoti (2016) developed a maturity model for SCC. The proposed model used existing literature on SCC antecedents and activities to define the stages of SCC, and created five maturity levels accordingly:

Maturity level	**Characteristics**
1. Initial	SCC processes are ad hoc and chaotic. Success is dependent on individual initiative and skills, not on the use of proven processes.
2. Managed	Basic SCC activities are performed, antecedents for the key activities. Planned processes, mostly reactive performed and controlled.
3. Defined	Key activities of SCC are established and executed as standardized processes that are proactively and consistently managed across the organization.

4. Quantitatively managed	Strategic level management where integrated and coordinated strategies aim at achieving the overall SC performance between multiple parties.
5. Optimized	Continuous improvement, both incremental and innovative improvements. Maximum SC effectiveness goal.

In such models, it may be assumed that a company desires to reach the highest maturity level with all their customers. However this is not always the case, since customers have very different service strategies which cannot always be aligned to higher maturity levels. Also TNNL might be hesitant to perform close SCC with its customers due to a lack of mutual trust. Because at higher stages of SCC, key activities such as information and risk sharing are involved.

When applying the characteristics of this model to the SCC of the repair service, it is in between maturity levels 1 and 2. The interaction with the customers is reactive in between states, only when the part enters a new state in the process the customer is updated automatically. Although there is a standard service desk procedure describing contact with customers, it came forward in the interviews that it is not always followed and that the contact is still unstructured and ad-hoc. “Every employee logs information differently and uses different descriptions for the same terms. Currently Sales support employees cannot take over orders of each other, because each employee logs information differently (Appendix A.2).”

At maturity level 2, there are antecedents that can best be described as the foundation for SCC activities. A total of 7 antecedents are mentioned:

1. **Managerial support**: collaboration has strategic commitment from the management.
2. **Internal alignment**: operations are streamlined to create value for the customer.
3. **Resource investment and development**: capacity, personnel, employee training, etc.
4. **Relationship building**: long-term interaction to create mutual trust.
5. **Information flow & system integration**: establish systems for sharing real-time, accurate, confidential, and relevant information.
6. **Formalization**: create explicit procedures to guide process execution and decision making.
7. **Rationalization**: managing and eliminating unnecessary complexity in the process.

For redesigning the repair process flow, four of the seven antecedents are in the scope of this research and are relevant to consider: internal alignment, information flow & system integration, formalization, and rationalization. The first two are included in the design of a communication structure between departments to improve the information logistics in the process, which is mostly derived from interviews and an analysis of the current repair process flow. The latter two form the basis for process design: where can rules and work standards be included in the process and what complexity can be removed from the process to focus on value-added activities.

2.3 Process design

For the process design, best practices from literature are derived to support the redesign of the process flow. First, opportunities for formalization are discussed to identify process steps where more standardization can be realized by adopting Standard Operating Procedures. Second, a technique for rationalization is discussed to evaluate the steps of the current repair process flow critically.

2.3.1 Formalization

When comparing the current repair process of TNNL in a production setting, it can best be compared with a make-to-order (MTO) production strategy, since at order placement, repair activities have not started yet and some components might have to be ordered first. According to Zorzini, Corti, & Pozzetti (2008), the lack of homogeneity of MTO contexts and the challenging task of formalizing decision mechanisms for managing customized products makes it difficult to develop processes and procedures with general validity. This is because the available literature does not sufficiently describe the, often ad-hoc, managerial practices actually employed by firms. Therefore the characteristics of repair process steps must be analyzed separately, to realize where more standardization in the process is achievable.

Standardization related to product design characteristics:	**Standardization related to process choice:** **Low** General technology, broad work content, labor intensive, decentralized control	 **High** Dedicated technology, narrow work content, capital intensive, centralized control
Low Unique products and custom designs	Case 1 – Work process standards: Indirect standards for both task inputs and operating procedures, e.g. through skills, organization, information and communication.	Case 2 – Work process standards: Indirect standards for task inputs, e.g. through skills etc. Direct standards for operating procedures, e.g. through SOPs.
High Standard products and fixed designs	Case 3 – Work process standards: Direct standards for task inputs, e.g. through specified designs. Indirect standards for operating procedures, e.g. through skills etc.	Case 4 – Work process standards: Direct standards for task inputs, e.g. through specified designs. Direct standards for operating procedures, e.g. through SOPs.

Figure 5: types of work process standards given product design and process choice.

This diagram of Berger (1997) denotes different types of standards for work processes as a function of the degree of standardization in the product design and the process choice. For low standardization, indirect work process standards are more applicable where there is room for own interpretation. For high standardization, direct work process standards are used to guide decision-making such as checklists or formalized procedures.

When applying the diagram to the repair process of TNNL, starting with the product design characteristics, the standardization potential for TNNL is low because of two reasons. Firstly, the products are not standard because the product designs change over the years and can differ considerably per customer, for instance due to obsolescence of components, technological innovations or specific customer requirements. Secondly, the task inputs, incoming parts for repair, have symptoms of failure that must be inspected before the required repair jobs are known. Analyzing and testing parts to find the failure is not a standard process. Therefore, an indirect work process standard for task inputs is suitable, where for instance skills and tacit knowledge of employees is needed (Michelberger, 2015).

In the operations of the repair process is more room for direct work process standards, because once the failure is found, the repair or replacement activities can be determined and planned upfront. Direct standards could be established, for instance, by designing and adopting standard operating procedures (SOPs) to create more uniformity in the process during repair. Concludingly, case 2 seems the most applicable to the repair process flow of TNNL, where '*unique products with custom designs*' is combined with a '*process with dedicated technology and narrow work content*'. This is confirmed by the article: it mentions processes around machinery maintenance as an example applicable to case 2.

From the interviews, it came forward that TNNL's repair service currently lacks an implementation of direct work process standards. Employees log and communicate information in different ways, leading to confusion and ambiguity at other departments. Some procedures for communication during the process have been established, but the coordination and management of these procedures are missing (Appendix A.2). So case 1 is most applicable to the current state of the repair service, while case 2 is desired by the management in the short term. In the long term, TNNL wants to standardize their product designs further, so that direct standards for task inputs can be realized, like in case 4. However this is a long transition process, because the product life cycles can span over more than 30 years. In this transition, it is possible that the work process standards for task inputs are split in direct for new standardized products and indirect for older unique products. However, in the short term, the focus is on establishing direct work process standards in the operations of the repair service, for instance through Standard Operating Procedures.

Standard Operating Procedures

SOPs are formal documents explaining how individuals or a group of individuals perform tasks and document the relevant information of tasks (Albareta & Mursanto, 2019). They are safeguards for ensuring that processes and activities occur as they should, so that they yield the same results every time (Gough & Hamrell, 2009a). According to Lubis et al. (2020), organizations need SOP in a standardized process to minimize the occurrence of work process errors. A SOP procedure functions as a reference and can smooth business flow between employees, work units, and related parties in the supply chain. A simple example of a SOP in a car tire Repair shop can be seen in Figure 6.

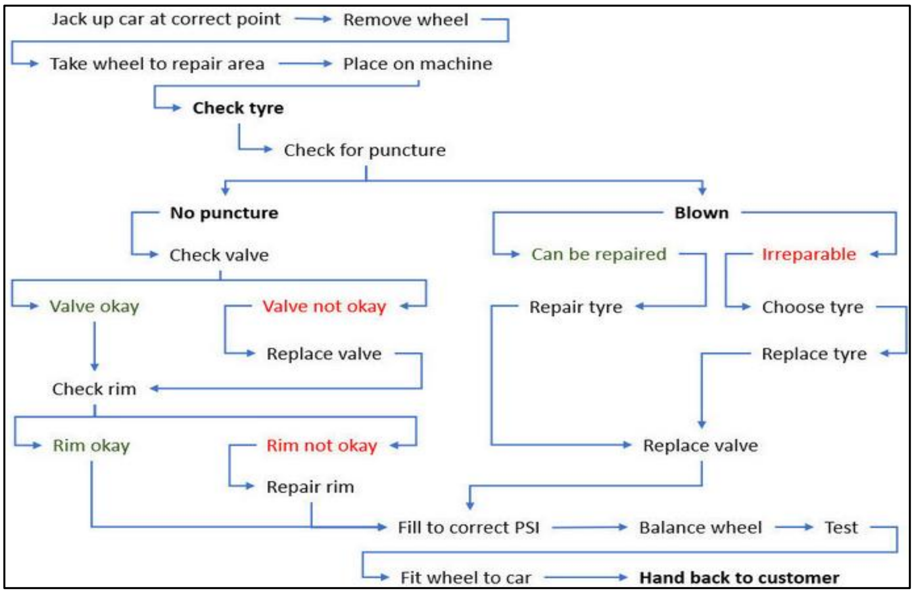


Figure 6: Car tire SOP example.

In order to establish effective SOPs, they should be written by or in collaboration with someone with hands-on experience on the processes. People involved in the process are an integral part of determining the content, because they have the best perspective of what needs to be included in a procedure to ensure that it will be useful to all who follow it (Gough & Hamrell, 2009c). Otherwise critical parts of the process could be missing, while other parts are overly detailed and eliminate the flexibility some processes require (Gough & Hamrell, 2009a). Furthermore, the most effective procedures are written in active, verb-driven and concise language (Gough & Hamrell, 2009c).

To remain relevant and up to date, procedures like SOPs need to be reviewed at regular time intervals to ensure they continue to reflect actual practices, because processes will change as the personnel, practices and medium change. Outdated procedures are more often to be neglected because workers have found better ways to carry out processes (Gough & Hamrell, 2009a). In order to keep the procedures for the processes correct and relevant, companies need to build in a system for procedure management, consisting of a series of steps to review the current procedures periodically (Gough & Hamrell, 2009a).

A good way to define which activities must be included in SOPs is to chart the flow. In this way, a business process model can help with compiling a set of activities for a SOP. Furthermore it can help with eliminating gaps and identifying overlaps of process activities in SOPs, meaning that an activity is not described in any related SOP or an activity is described in more than one SOP (J. Gough & Hamrell, 2009b).

In conclusion, SOPs seem suitable for activities in the repair process that can be standardized and are repeatable. For exchanging information between departments and with the supply chain during the actual repairment, direct standards are helpful to ensure compliance and coordinated planning. It is however important that the SOPs are designed and established together with workers that have experience with the processes on a day-to-day basis, and that the procedures are evaluated periodically to prevent them from getting outdated. To design SOPs, modelling the process flow can contribute to selecting the relevant set of activities. Therefore, the resulting business process models of this research can be helpful for TNNL when designing SOPs in the repair process.

2.3.2 Rationalization

When redesigning a process, it is helpful to evaluate the current process steps with their objectives to identify and eliminate non-value added activities and unnecessary complexity (Gunasekaran & Kobu, 2010). This method, called rationalization, can be useful for critically evaluating the current repair service design.

The paper of Meier & Massberg (2004) raised a theory for rationalization in service design by splitting the process flow into separate modules. With this modularization of the process, it can be judged per product or product group which service modules are required in the repair process flow, based on product-specific characteristics. With a customized repair process flow for particular product categories, modules with unnecessary complexity can be excluded, which simplifies the process. Overall, leading to a competitive service product range through standardization, rationalization and automation (Meier & Massberg, 2004).

3. CURRENT PROCESS FLOW OF THE REPAIR SERVICE

3.1 Internal repair stream

From the interviews, the repair process is modelled as it currently is executed, also called the IST situation. For this, the BPMN standard is used, see Appendix C for an explanation of all elements in the models. The process flow is split in three parts, based on the three phases of the repair process: the RMA process, the inspection process, and the repair process. But first, an overview is given of the information systems that are involved in the repair process:

- **Oracle** is the ERP system of TNNL. In the repair process, Oracle is used to document the logistic information of a part and status updates. Once a week, data of all repair cases is extracted from the system by Sales support and put in an Excel file. When a customer asks for an update, the Excel file is the first source that Sales support consults by looking at the supply chain comments in the list corresponding to the repair case. In the Repair shop, Oracle is used to assign tests and repair jobs to engineers in a work cell.
- **FRACAS** (Failure Reporting, Analysis, and Corrective Action System) stores all technical information of a repair case: what is the failure of the part, how to repair it, and how it is eventually repaired. From the technical information in FRACAS, the *FAR* (Failure Analysis Report) is compiled that is send to the customer with the quotation. Also, when the repair is completed, the *FARR* (Failure Analysis Repair Report) is compiled using FRACAS to inform the customer on the performed repair activities. In a couple of months, FRACAS will not be used anymore, because TNNL wants to reduce the number of information systems. They are currently assessing what information from FRACAS must be integrated in an information system elsewhere, in Oracle or Windchill (Appendix A.5.1).
- The **Customer Portal** is a platform that was introduced two years ago to facilitate service management and communicate structurally with customers instead of mail and phone contact. In the portal, all information regarding the status of a repair can be found by internal departments and the customer. However, a large share of the customers does not access to the CP yet, because license agreements must be included in the service contract and most contracts have been drawn up before the introduction of the CP. For these customers, the CP is only used internal by the CCC to have the status of all repairs in one place.
- **Windchill** is the Product Data Management (PDM) system that stores technical information of the product design phase, such as indenture levels of the system and the service strategy for the system, including repair or replace decisions of components. This information is currently limited utilized in guiding decisions in the repair process, see Appendix A.7 and Appendix B.

RMA process (Figure 7)

The start event is an incoming repair request (RR) of the customer, which can arrive via mail or via the Customer Portal (CP) if the customer has access to it. Sales support takes care of the correct registration of the RR in the CP. After that, a Customer Contact Center Engineer (CCCE) analyzes the technical information of the part following a checklist using information from Oracle and Windchill. If the part is repairable, the engineer approves the RR and opens a FRACAS case. Subsequently, Sales support can retrieve an RMA in Oracle and send it to the customer.

When a customer does not provide enough technical details about the failure, the CCCE cannot make a proper decision whether the part is repairable. In this case, Sales support requests the customer for additional information. There are incoming repair requests that cannot be approved by TNNL, for instance for parts that are more costly to repair than to buy new or the service lifecycle has ended.

Inspection process (Figure 8)

With the RMA, the customer can send the part to TNNL. It can take months until the customer actually sends the part, for instance due to a lack of urgency or a failure at open sea. When it arrives in the expedition, the Repair shop is directed to pick it up and perform visual inspection on the part. The reason of the visual inspection is to check if the part is not too damaged for repair and to make photos to document the state of the part upon arrival. After that, the external repairs are split from the process and follow a different process flow. For the inhouse repairs, the Repair shop allocates the part to the right engineers work cell for testing. These work cells have their own specialty, for instance there is an electrical work cell for testing components like printed circuit boards assemblies (PCBA's), etc. When the tests are performed and the failure is found, the required repair jobs are determined and reported to the customer in the FAR. Based on the FAR, Sales support draws up a quotation and send it to the customer.

Repair process (Figure 9)

When the customer accepts the quotation and places a purchase order, the repair activities can start. For some parts, new components are needed to replace instead of repair the broken ones. If these components are not in stock, they must be ordered first by the Purchasing department. The Repair shop must wait on the arrival before it can assign tasks to an engineer work cell. The planning is currently ad hoc for most work cells, this implies that there is no logic in place to prioritize tasks and the tasks are planned only a couple of days in advance.

When engineers perform the jobs, they log a short job description in the FRACAS case. When all jobs have been executed, the part is tested again to check if the repair succeeded. This is necessary, because the repair process involves some trial and error. There may be unforeseen failures that become apparent after performing the initial repair that require extra repair activities and/or components.

The logging of information is not done systematically. It came forward that information was sometimes logged in FRACAS by the Repair shop instead of the engineer (Appendix A.4). This is second hand information which tends to be less detailed and precise. Also the description is sometimes too limited or ambiguous (Appendix A.2). In this case, Sales support has to contact the Repair shop for clarification, distracting them from their work activities.

When the repair is completed, the Repair shop compiles the FARR to report to the customer which repair activities have been performed. Then, Sales support marks the repair case as closed in the information systems and prepares the required shipment forms for the expedition. The processes at the expedition are not modelled because they are not affecting the repair process flow. Their task is just to inform that a part has arrived and to ship the part after repair completion.

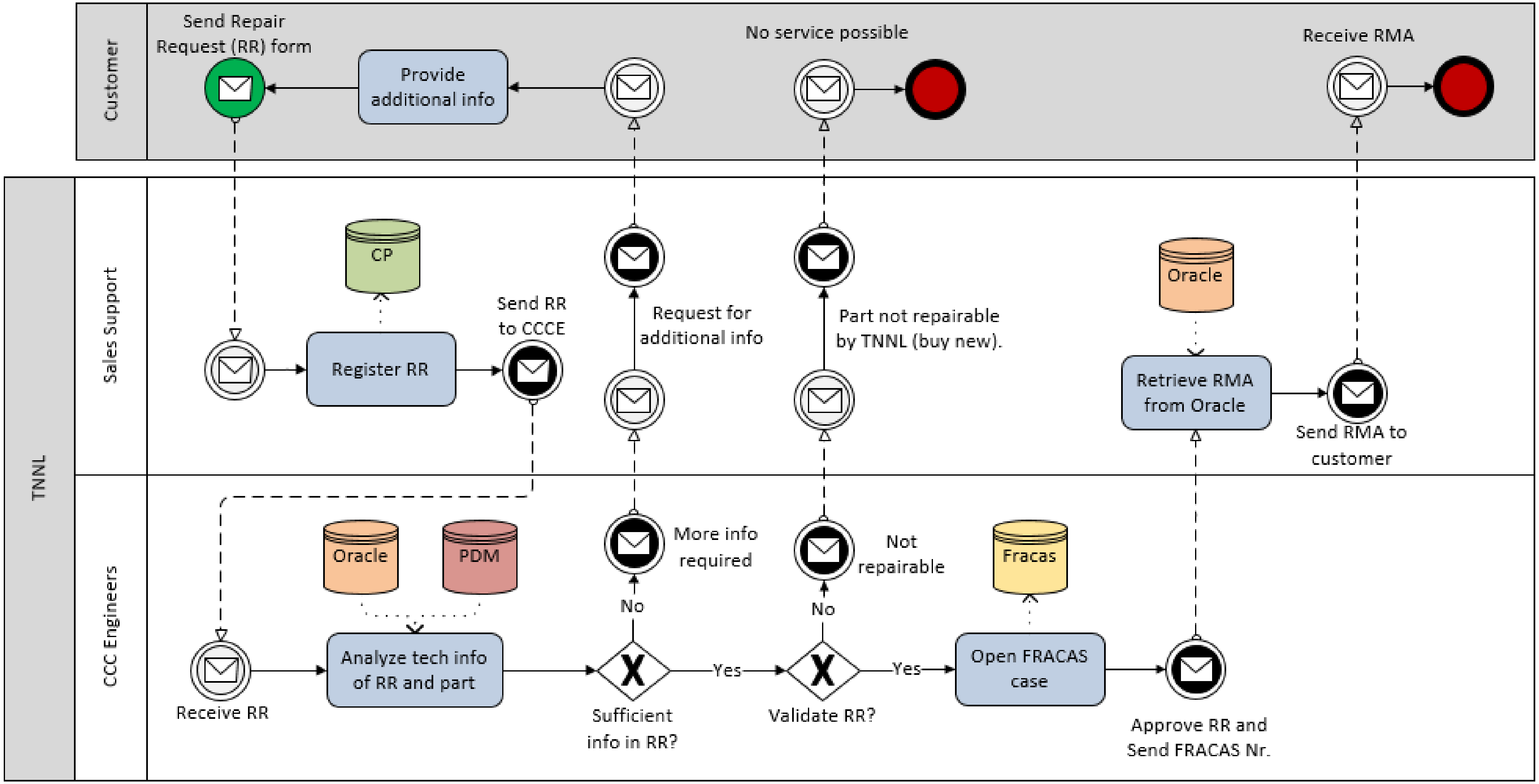


Figure 7: IST - RMA process flow.

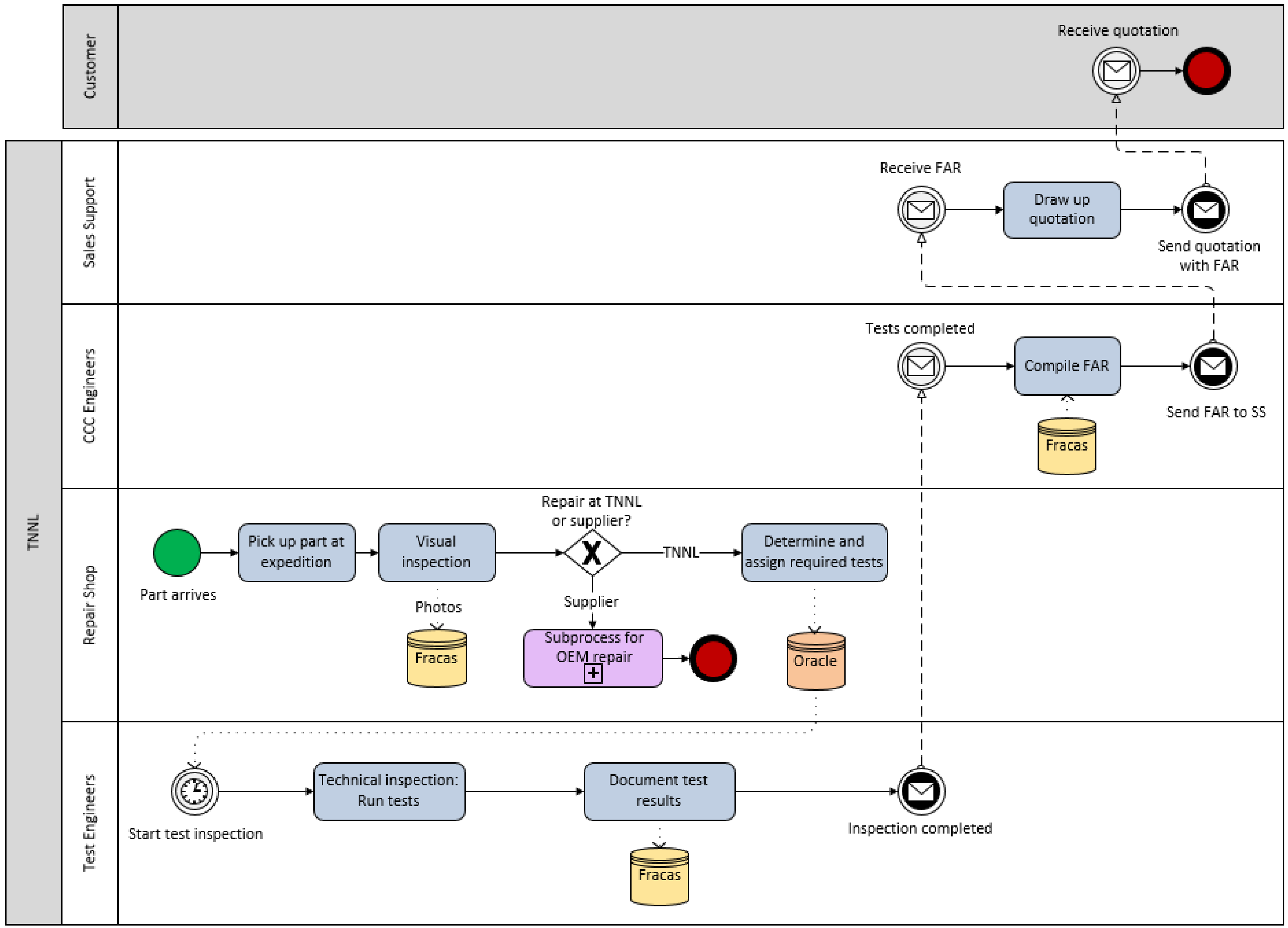


Figure 8: IST - Inspection process flow.

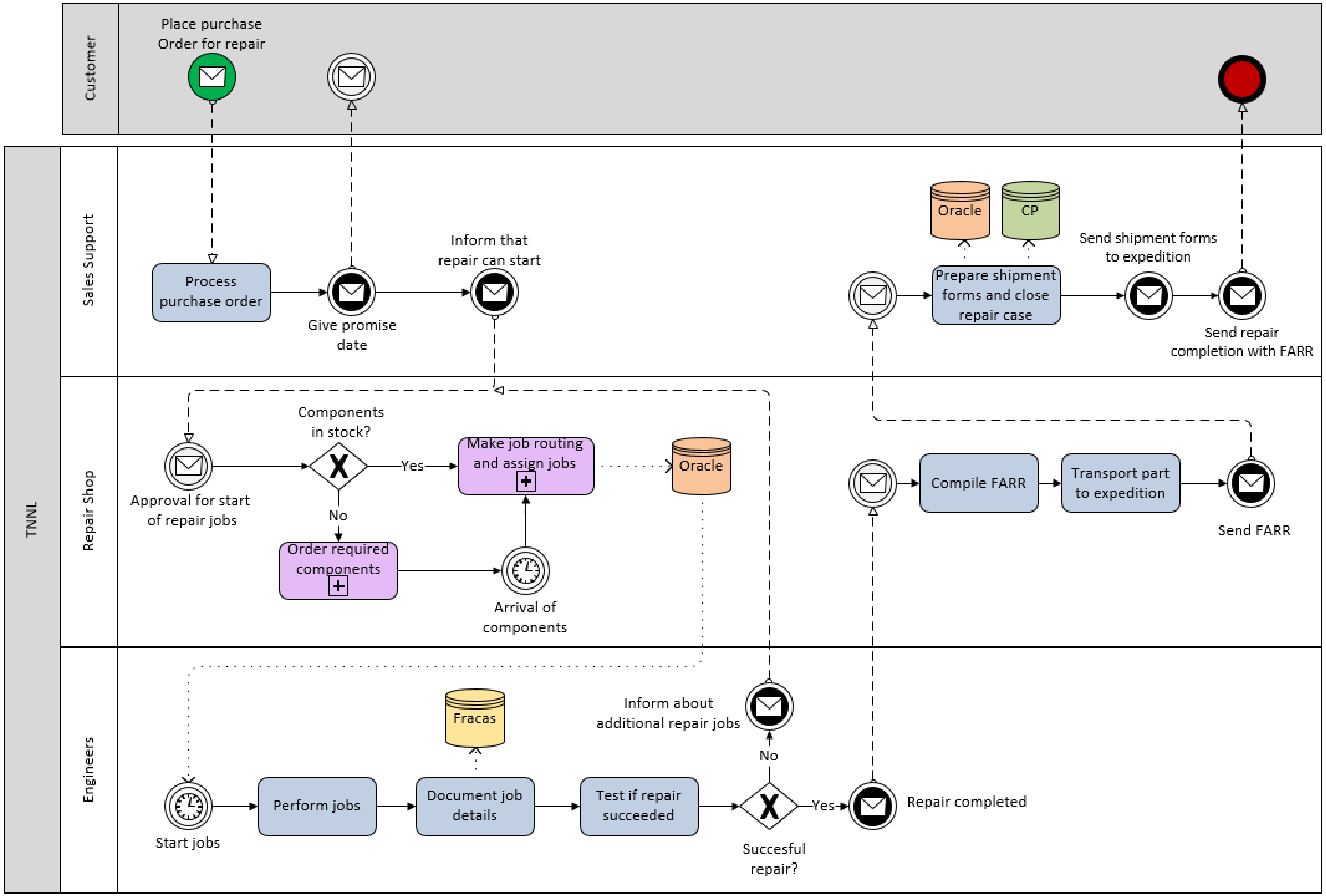


Figure 9: IST - Repair process flow.

3.2 Status updates during the process

At the Repair shop, supply chain information from repair cases is documented in the ERP system, containing where in the process the part currently is. Once a week, all this data is extracted from Oracle and put in an Excel file. This is the first source that Sales support consults when a customer asks for an repair update, where they search the supply chain comments in the list corresponding to the repair case. However, the problem is that these comments are not filled in sufficiently or not at all for some orders. If this happens, Sales support contacts the Repair shop by mail or phone to retrieve a status (Appendix A1). The subprocess of retrieving a repair status is ad hoc and can involve various activities: checking Oracle for information that Sales support cannot access, contacting the responsible engineer work cell and searching on the shelves. For external repairs, Purchasing is contacted to retrieve a status from the supplier. This process is depicted below in Figure 10.

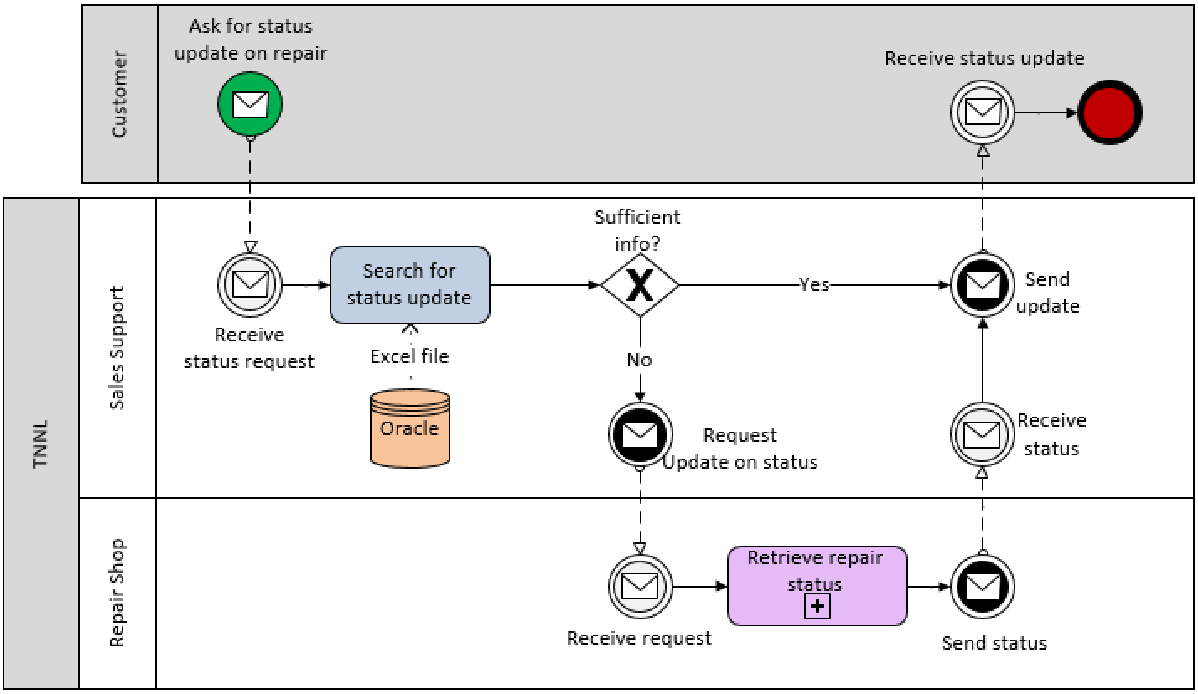


Figure 10: IST - Status request process flow.

3.3 Analysis of current repair process

If we evaluate the information and communication structure in the repair process flows based on the gathered literature on this subject, several improvement points are identified that will be formulated in requirements for the design of the improved model, also called the SOLL situation.

Internal information structure

The only information source Sales support can consult is an Excel file extracted from Oracle, which is updated only weekly, so there is no access to real-time information and technical information that is documented in FRACAS during tests and repair activities. Relevant progress updates that are already stored in internal information systems is therefore not shared with Sales support. Subsequently, they are unable to establish a proactive information flow to the customer. Furthermore, there are multiple forms of contact between Sales support and the Repair shop, via mail, phone and Excel files. To improve this, these information logs should be accessible and centralized for all process participants in an information system during the process. For status updates on repairs, the CP could be suitable to gather all information per repair case. The Repair shop could adopt logging in the internal CP to report when the status of a repair is updated. These are standard points in the process: part arrival, inspection completion, job planning, repair completion and retour shipment. Also when components are required that are not in stock, the lead time of the supplier could be communicated. In this way, the CP could be used to organize relevant updates about the repair case in one place instead of using chaotic mail contact.

The technical information and the logistic information of the repair process is currently split up between two system: FRACAS and Oracle respectively. TNNL will not be using FRACAS anymore in a couple of months, instead the technical information will be included in Oracle. This gives opportunities to centralize repair information and make it more accessible for process participants.

Customer satisfaction on services

The above mentioned problems in the internal information structure have its effect on the service satisfaction of customers. There are missed opportunities of providing operational transparency to the customer at the above mentioned standard points in the process. No infrastructure is in place to systematically pass these updates through to the customer.

Secondly, the propositions of perceived waiting time can be better applied in the repair process. It is not standard communicated with the customer what the reason is for a delay, for instance if the repair must wait on components or other resources. By justifying these delays, customers are less likely to be dissatisfied than if there is no explanation given. If components are ordered at the supplier, the expected lead time for TNNL should be provided to the customer to give a certain duration to the delay. Furthermore, customers should be informed at the start how the repair process proceeds and what value is added in the process phases. By getting a better understanding of the value added activities and more familiarity with the process, customers are more willing to wait.

Also, the customer should be more involved in the decision making when irregularities occur in the inspection or repair phase. For instance, when TNNL cannot find the failure in the part with its test equipment or the failure is still not resolved after multiple repair jobs or replacement. Currently, the decisions are mostly made internal with the possible result that the customer is not satisfied with the outcome or costs.

Inspection and repair process

The illustration of the process flow in the Repair shop and Engineer work cells is solely based on the interviews. There are no procedures or process flows written down or formalized to get everyone on the same page of what the repair process flow is. This also came forward in the interviews, there are different views on how the process is followed. The process is mostly ad hoc here, which also applies to the test and repair job assignment in these departments: there is no planning and parts are piled up at work cells after job allocation.

At this realization, I deviated from my original research goal of improving the information logistics< because I found a cause for my initial core problem: the poor information logistics in the repair process are caused by the absence of a standard repair process flow. So besides designing the information logistics structure during the process, this research will also on creating a standard process flow that fits the repair cases.

Repair by replacement

It came forward in the interviews that the process flow is not strictly followed for one product group: Printed circuit board assemblies (PCBA's), which are repaired directly during the technical inspection. The components of PCBA's are in stock or can be supplied within days and cost only a couple euros. The Repair shop argues that it is no use to wrap the part up and put it back on the shelf to wait for order placement, but that it is more logical to replace the component directly so that the failure is fixed (Appendix A.5.1). However, by repairing parts before the customer places a purchase order, TNNL runs the risk that the customer rejects the quotation and that the part is returned completely repaired without incurring repair costs.

Therefore a different process flow is required that fits a repair by replacement strategy, enabling direct component replacement during test inspection. In this process flow, the TNNL should be able to give a price quotation before inspection (and direct replacement) to avoid rejection afterwards. This can be feasible, because component costs and the work hours for replacement can be estimated upfront. Also for other product groups that are normally repaired by replacement at component or SRU level this process flow may be better.

The difference between replacement at SRU or component level is that replacing components involves more trial and error, because the test equipment cannot always deduce the failure to a single component. By replacement on SRU level, a whole module of a part is swapped. In the product design phase, the optimal indenture level of replacement is determined, see Appendix A.6.

To conclude, it is expected that this rationalization of the repair process flow results in a simpler process with less uncertainty, since no action from the customer is required in between, where TNNL has to wait on the customer to place a purchase order.

4. DESIGNED PROCESS FLOW OF THE REPAIR SERVICE

From the observed improvement points in the analysis of the IST situation, requirements for the SOLL situation can be formulated that are included in the process flow design.

- Split the repair process flow for Complex repair and Repair by replacement.
- For parts that follow the Repair by replacement strategy, a fixed price for service must be accepted upfront, enabling replacement during test inspection.

Information logistics requirements:

- Inform the customer upfront about the process the part will follow to manage expectations. By making customers aware of the value the service adds, they are more willing to wait.
- Internal information exchange about repair status updates should follow one central internal information system to make it centralized, real time and accessible for all stakeholders.
- From reactive to proactive communication in the process. Document information at standard points in the process (such as part arrival, supplier's lead time for required components, job planning, repair completion and retour shipment). And update the customer on the repair status at these standard points in the process flow.
- For complex repairs, agree on a time window for periodic status updates to maintain transparency. Agreements bring structure in the communication with customers and reduce reactive incoming status requests from customers during the repair service.
- Communicate promise date to customers after planning the repair activities.

In the designed process flow, the inhouse repairs are split in two repair streams: Repair by replacement and Complex repairs. Which repair stream a system must follow, also called the repair strategy, is decided during the design phase of the product lifecycle. This data is already there for most of the products, but it is not utilized effectively to guide repair decisions. In Appendix A.7, an interview is conducted with a logistic engineer to get a better overview of the available information from the design phase that is insufficiently used during the service phase of the product lifecycle. The current ratio of incoming repairs per repair stream can be seen in Figure 11.

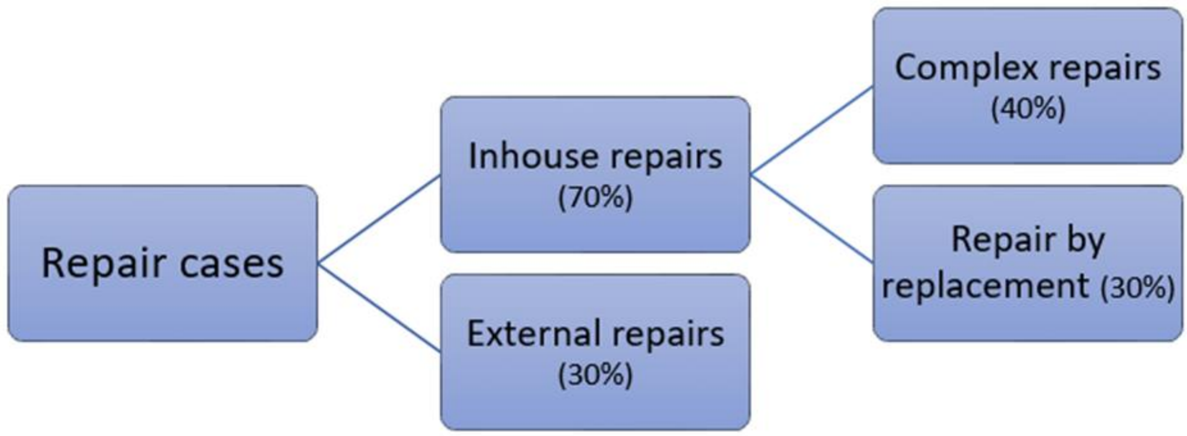


Figure 11: The current ratios of the three repair streams.

4.1 SOLL situation

In the SOLL situation, it is assumed that a capacity planning is established for the engineer work cells to demonstrate the possibilities it gives in terms of communication to the customer.

The involvement of information systems slightly change compared to the IST situation. The technical information from the FRACAS system is integrated in the ERP system to make it more accessible and centralized for process participants. Also, a distinction is made between the internal and external CP in the model (iCP & eCP), because the CP will be used more in the process. New information in the iCP alerts Sales support to transform it in an update suitable for the customer. For instance, when a planning for repair activities is made by the Repair shop, they can communicate a promise date in the iCP that Sales can put through to the customer.

In each repair stream, the customer is informed upfront on the process the repair is going to follow. This includes the repair strategy and the current crowdedness of the system. Also an update interval is proposed to the customer about the repair status, this should be internal aligned and may be aligned to other repairs of the same customers so that a list of status updates can be provided at once. During the process TNNL should contact the customer when there are unexpected delays in the process, for instance if replacement components are out of stock.

Repair stream split (Figure 13)

After the registration of the repair request in the customer portal, technical analysis on the part is performed. The difference with the current situation is that the CCC verifies upfront what repair strategy has been chosen for this part in the product design phase. With this information, the part gets designated to a repair stream with an appropriate process flow.

Repair by Replacement stream (Figure 14)

The process flow starts by informing the customer on what repair stream the part will follow and by sending a fixed price quotation for the service. Only after the customer places an order, the RMA is given for shipment of the part. So that at arrival of parts the order is already placed, enabling replacement during test inspection. Also it may incite customers to send the part as soon as possible, since they already placed an order for the repair service. The change in phases and actions from the customer in between are depicted in Figure 12.

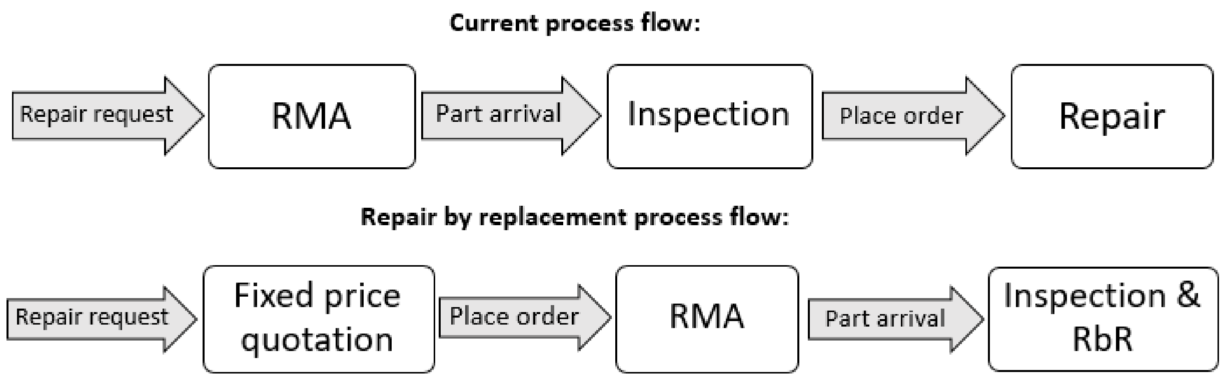


Figure 12: Change in phases of the process flow for repair by replacement stream.

After RMA, without incidents or irregularities, the information flow to the customer is only at the standard points in the process: part arrival, job planning, repair completion and retour shipment.

This strategy comes with monitoring on two aspects. Firstly, it should be evaluated if the fixed prices remain profitable and if the estimated man hours are sufficient. In order to accomplish this, it is important to document man hours and component costs accurately. Secondly, inventory management plays a large role in this strategy, since TNNL must continuously monitor the stock levels of components of a system with this strategy to ensure that a replacement is on hand.

Complex repairs (Figure 15 & 16)

Complex repairs concerns all inhouse repairs which are not repaired by replacement of component or SRU's. For instance, older or unique products of which the components are obsolete or not profitable to replace. The complex repair stream follows the same phases as the current process. The focus here is mainly on making the internal and external information flow systematic and more proactive. The involved departments can aim more attention on establishing this for this repair stream, since the repair by replacement stream is simplified and less uncertain, requiring less coordination and communication.

At the start of the process in Figure 15, the customer is informed on what repair stream the part will follow and a time window for periodic status updates is agreed. This is helpful for complex repairs, because these repairs typically have a longer lead time, which has to be justified and explained to keep the customer satisfied.

External communication procedures (Figure 17 & 18)

In Figure 17, the standard procedure for Sales support is illustrated for transmitting internal information into a message for the customer. This process is triggered every time the repair status of a case is updated. In Figure 18, the process flow of periodic status updates for complex repairs is depicted. In comparison with the reactive process of the IST situation in Figure 10, it can be seen that status updates are now provided to the customer proactively. However, when there is not sufficient information in the systems for Sales support, a reactive communication flow is still required to retrieve information. To avoid this, the Repair shop and engineer work cells should be informed on the update frequency for the periodic status updates to log information accordingly.

Irregular situations in the process

To reach more operational transparency, TNNL should involve the customer more in decision making regarding their product. During the process, situations can arise that require consultation with the customer. These are mapped in the model using error events. When these irregularities occur, the process is terminated, a list of options is prepared and the customer is contacted by Sales support. Currently, TNNL makes these decisions mostly internal, sometimes leading to unanticipated high repair costs or an undesired solution for the customer. Examples are:

- If during testing, no malfunction is found by the test equipment of TNNL. Then the decision should be laid at the customer: return the part untouched, test the part on location in the customer's system or overhaul of the part.
- After multiple repair jobs, the failure in the system is still not solved. Consult the customer to make the decision: stop repair activities and order new, or continue with accumulating costs.

- If at visual inspection it turns out that part is beyond repair, e.g. due to burn or corrosion damage. TNNL should not continue the repair process against better judgement, but quit the process, contact the customer and give the opportunity to buy a new part.

External repairs

For external repairs, TNNL plays the role of intermediate between the supplier and the customer with the goal to align the agreements with the supplier to the expectations of the customer regarding updates on the repair status. After shipment to the supplier, it is difficult to influence the process flow and to track the progress of the repair. TNNL could try to make agreements with suppliers regarding communication, but it came forward in an interview that TNNL cannot put too much requirements on suppliers, because it has no leverage or contracts with suppliers (Appendix A.2 & A.6).

If more information or a better service is desired from suppliers, contract agreements are required that should be aligned to the service contract with the customer. So if TNNL provides ten years of service to a customer for a system, TNNL should express in the contract that the supplier can provide repairs for certain parts of the system in these ten years and are able to fulfil the customers' expectations in terms of transparency.

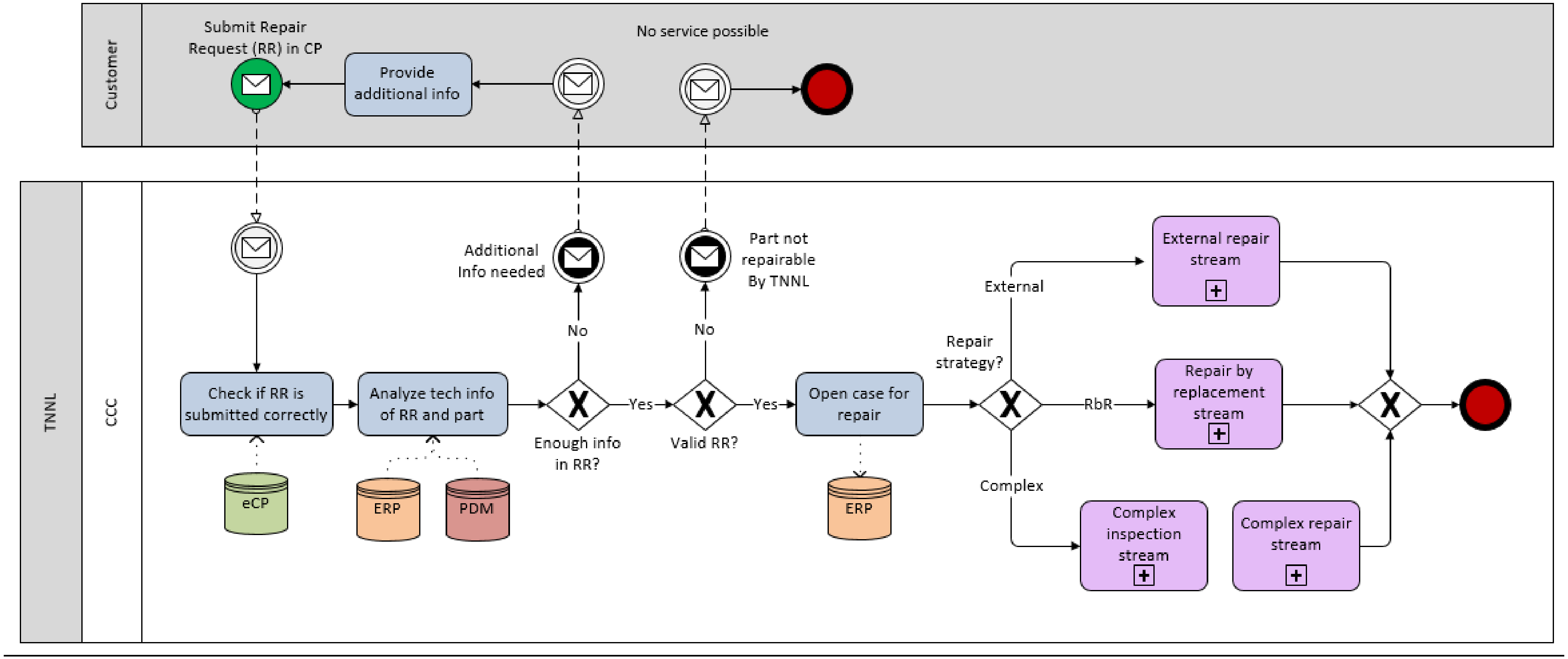


Figure 13: SOLL - Process split of the repair streams.

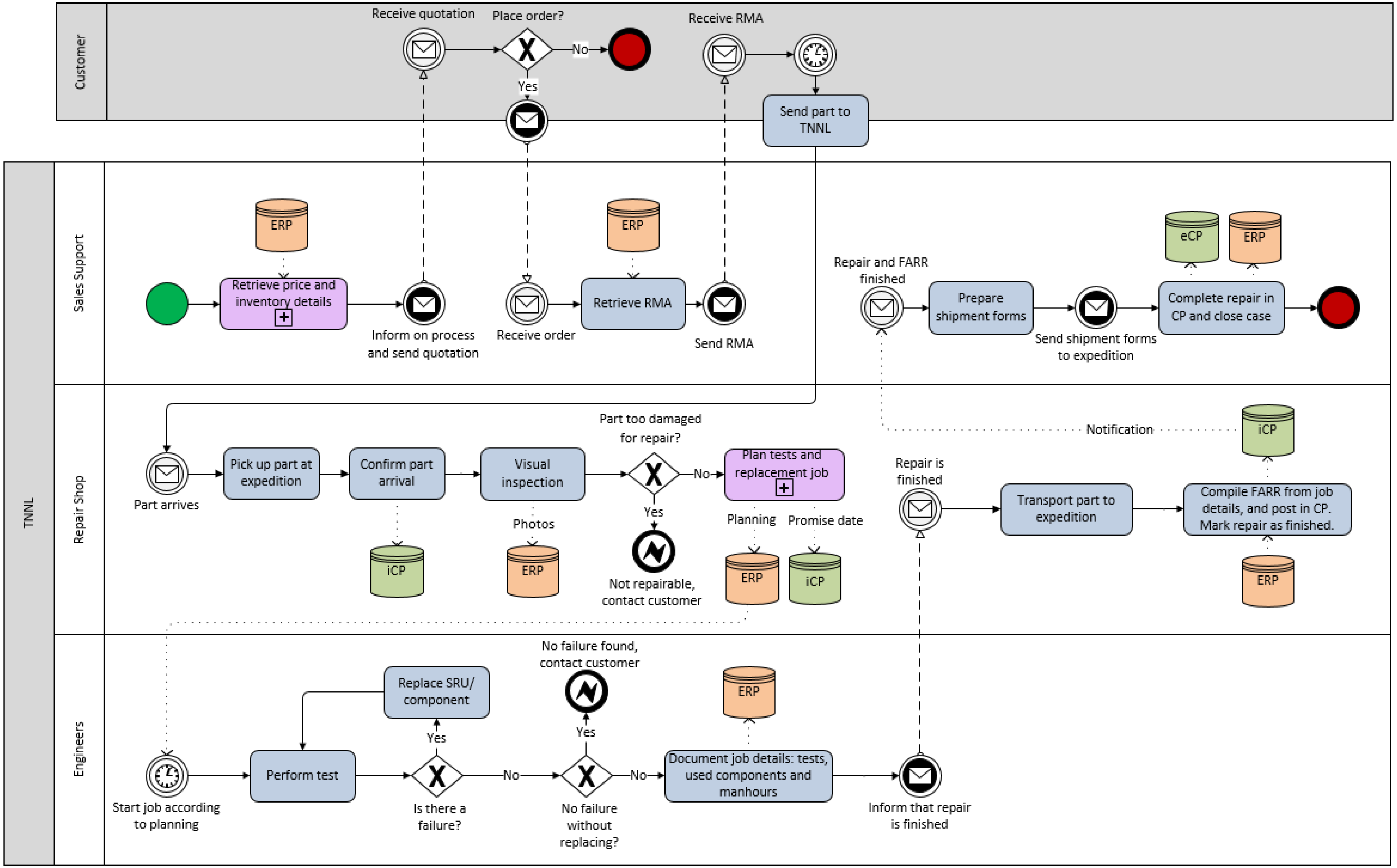


Figure 14: SOLL - Repair by replacement stream.

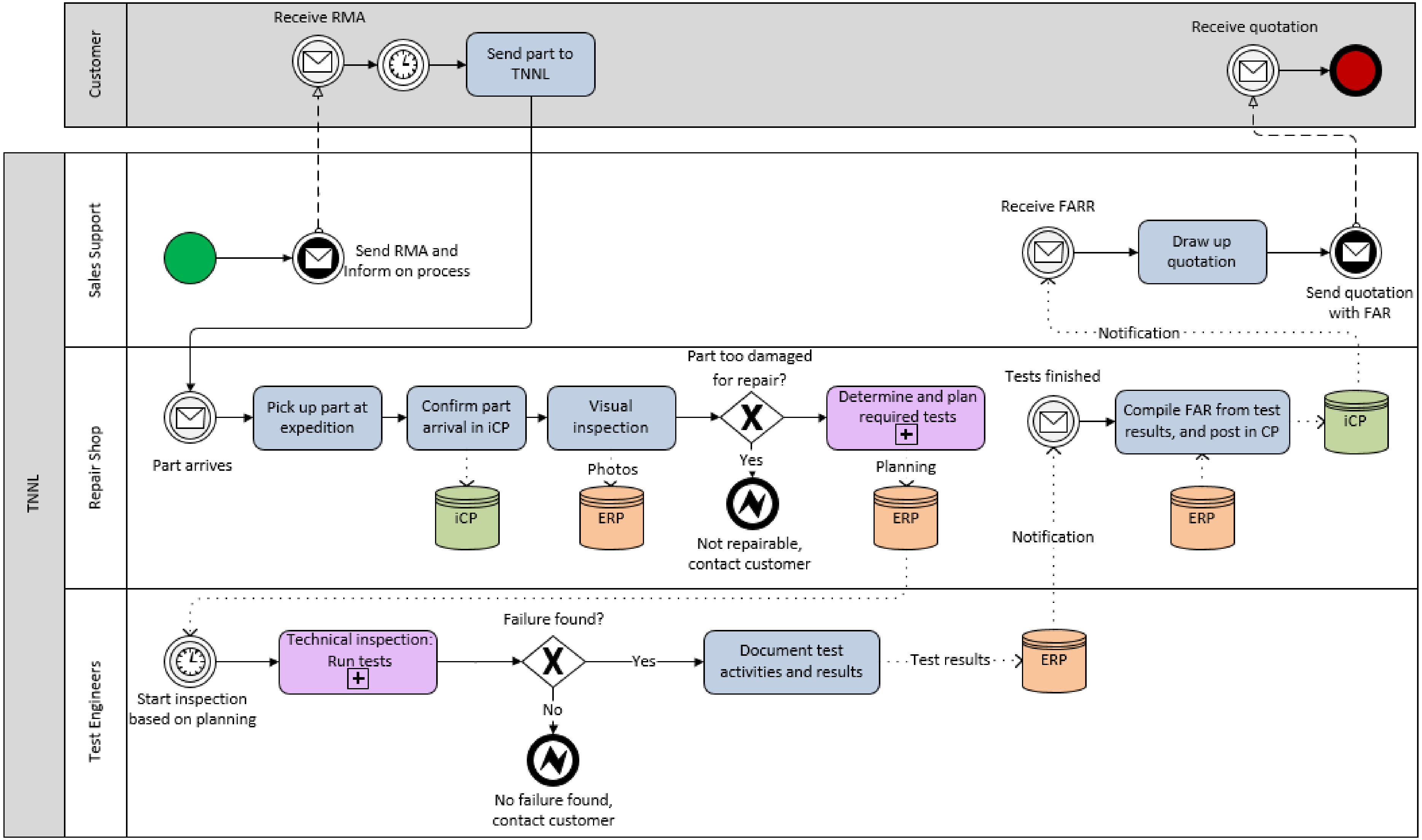


Figure 15: SOLL - Complex inspection stream.

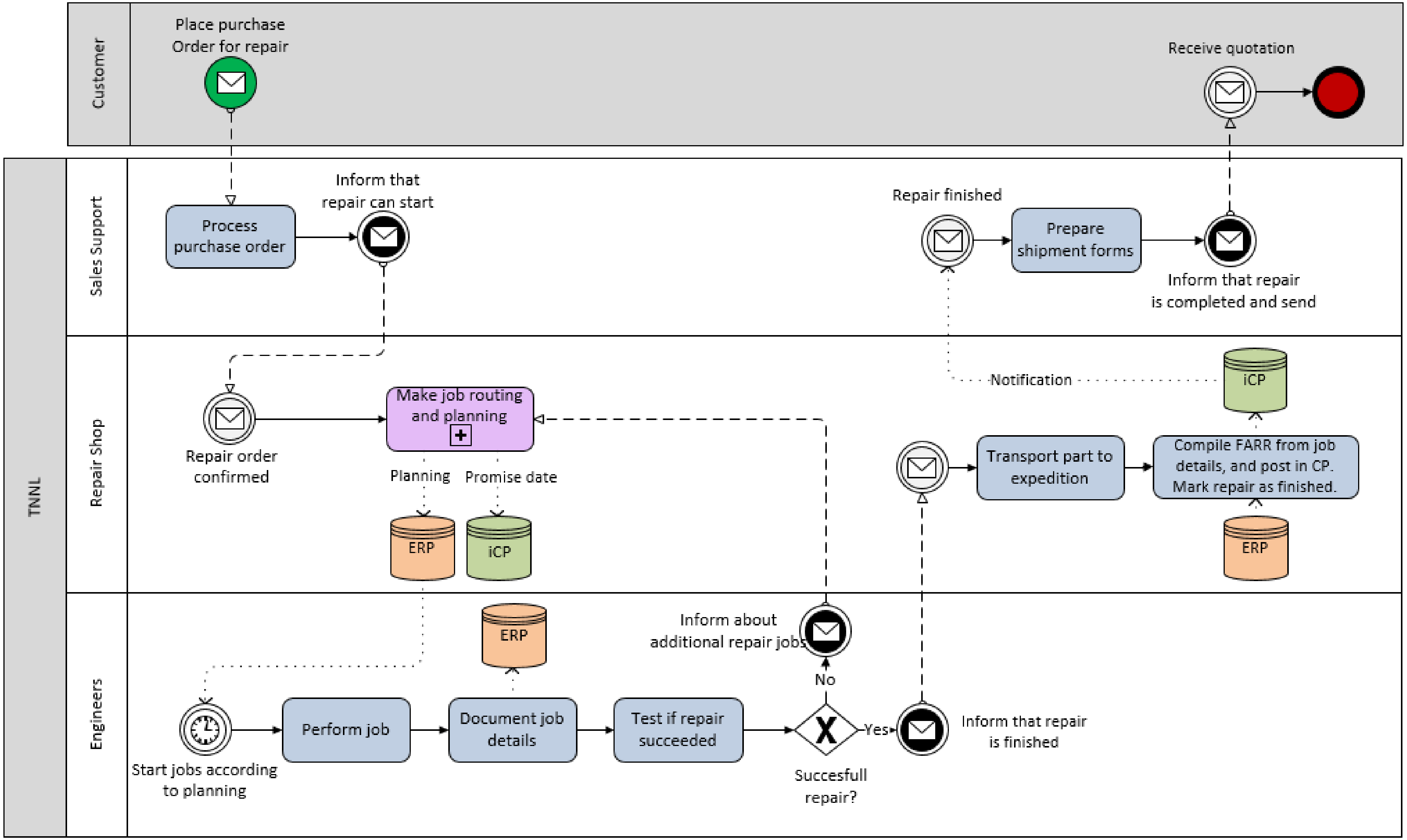


Figure 16: SOLL - Complex repair stream.

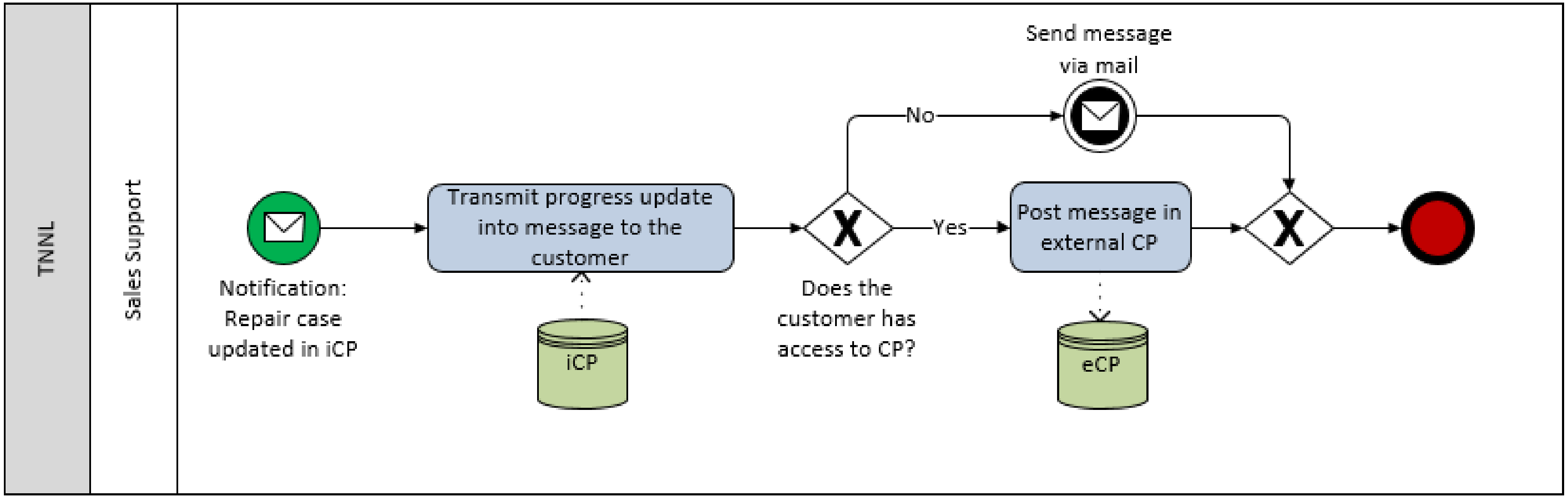


Figure 17: SOLL - Transmission of information to the customer.

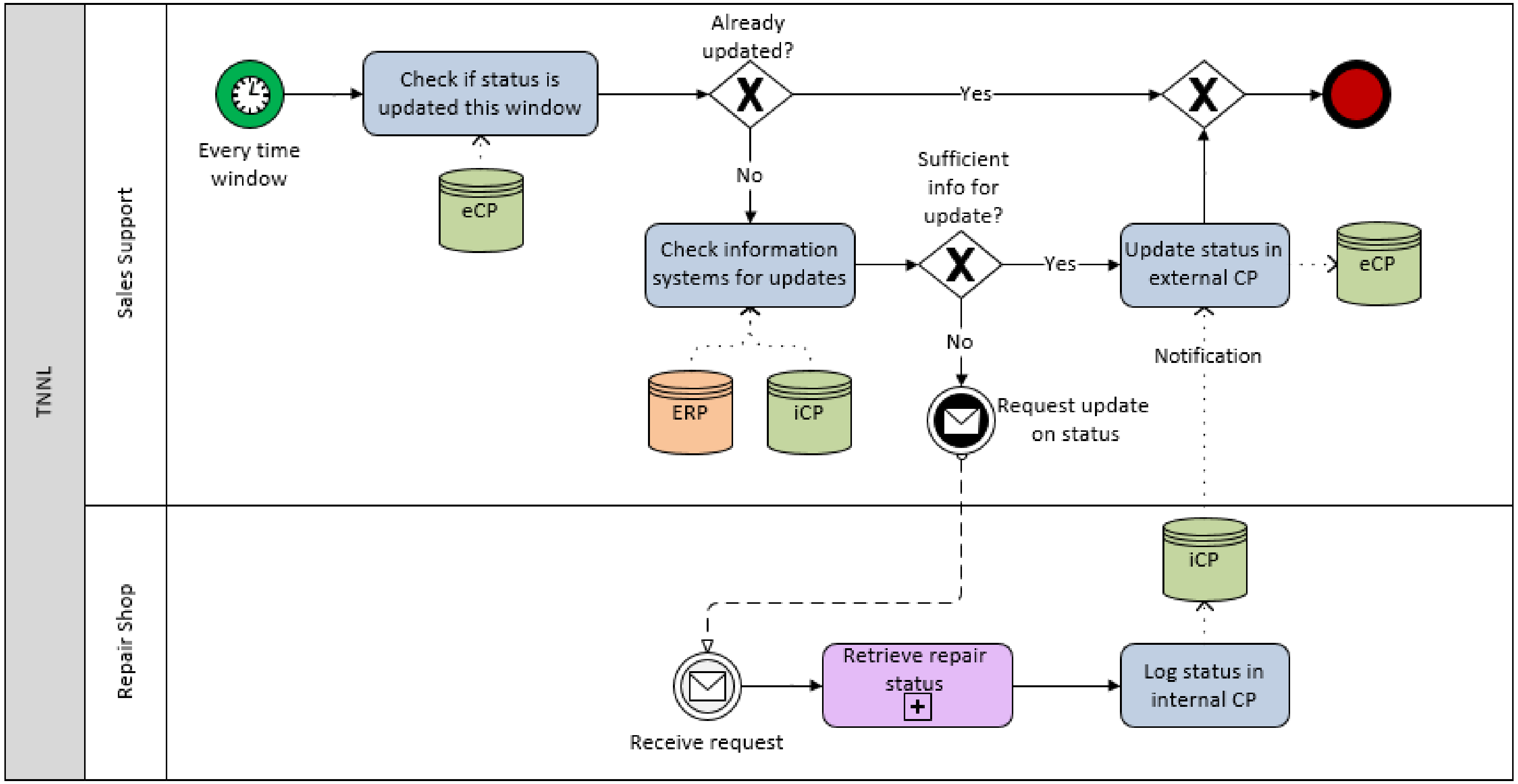


Figure 18: SOLL - Periodic status update for complex repairs.

4.2 Validation of SOLL model

The last task of the design cycle is validation of the designed model, by using the expert opinion method. For expert opinions, two participants from the CCC and two participants from the Repair shop are consulted in separate meetings. A further introduction of the participants can be found in the respective chapters.

These meetings start with a short presentation, where I present the problem identification of the current repair process flow, using the problem cluster of Figure 2, and the requirements for the solution design of the improved process flow. Then I briefly discuss the process flows of the designed model to demonstrate how the requirements are included in the process flow and what the changes are for their departments.

Based on this, participants can evaluate which effect these alterations have on performance measures of the designed model in comparison with the current situation. Also participants can share their own considerations on the designed model to identify attention points or important considerations, which may be included in the recommendations, discussion and suggestions for further research.

The performance measures are derived from the identified problems in the current repair process. In this way, the models can be compared and it can be validated if the process flow of the repair service is improved.

- *Repair lead time.* By establishing a standard for the repair process flow and information logistics procedure, it is expected that the process can be better monitored and efficiently executed. Also the routing and capacity planning that currently is being set up will contribute to an efficient work process and coordination. Furthermore, by simplifying the process flow for repair by replacement, it is expected that the lead time can be decreased especially for this product group, because no action from the customer is required in between inspection and replacement. Leading to less waiting time and better planning opportunities in the process.
- *On time delivery.* By determining a promise date after planning repair activities instead of after order placement, the planning can be taken into account for the promise date. Therefore, it is expected that it contributes to a higher on time delivery.
- *Information logistics*. By standardizing the information documentation and contact points with the customer during the process, it is expected that the designed model will improve the internal information logistics during the repair service, which in turn creates opportunities to give more transparency to the customer during the process.
- ***Customer's service satisfaction***. By reducing the lead time, increasing the on time delivery and improving the information logistics, the customer satisfaction improves on the repair service.

4.2.1 Expert opinion of Repair shop

The experts are a Supply chain manager of services and a Product support technician of repairs. Both are involved in improvement projects for the repair operations, such as the realization of job routing for all repairs and capacity planning in the work cells. They can validate if the designed model and its requirements have its desired effect on the performance measures. Also they can assess if the repair by replacement strategy is feasible and what the considerations are.

Repair lead time and On time delivery

They agree that there is much room for improvement in the coordination of operations in the repair shop and the engineer work cells. The standardization of the process flow can help with this by smoothen the process and giving insights in responsibilities. However, the concrete shape of this standardization has to be established yet by creating standard operating procedures in detail with the process participants. To support this process standardization, another critical part is the installation of capacity planning and job routing for all repairs, which is not concretely discussed in this research. This is a suggestion for further research on a more operational level of the repair process.

Information logistics

They approve the structure of logging information at standard points in the process and providing additional periodic updates to customers on an agreed interval. This is currently not performed correctly and consistently. Also the creation of a terminology for the status log is certainly needed to prevent ambiguity between process participants.

After establishing an information logistics structure in the internal organization, the next challenge is too engage suppliers in sustaining this information flow for external repairs.

There was one suggestion for the utilization of information systems in the designed model. In the model, the Repair shop logs status updates in the internal CP to fulfill the requirement of centralizing information about repair statuses in one system, so that it can be put directly through by the CCC to the customer in the external CP. However, the Repair shop is currently not working with the CP, they log updates in the ERP system instead. To avoid complexity, they suggest that the ERP system should be linked to the CP in a way that new status updates from the ERP system are automatically synchronized to the CP, so that the Repair shop does not have to work in multiple information systems.

Repair by replacement

They approve on the creation on a separate repair process flow that fits the PCBA product group, where components can be replaced during inspection without running the risk of quotation rejection by the customer. Using a fixed price is attainable for these repairs, but it must be defined when TNNL can incur additional costs, for instance if more components or man hours are required than expected.

An attention point is the distinction between the replacement of a whole part and replacement of components or modules of a part. For component replacement, there is still trial and error in the process, because the test equipment is not always capable of finding the exact faulty component and there may be other underlying failures that are not detected in the first test inspection. This research created a process flow focusing on replacing components or modules of a part. For replacing whole parts the process is different and gets even simpler, because a spare part can be send immediately after order placement.

Following this process flow for replacement results in a more efficient work process and it requires less man hours and administration, since replacement is a simpler and more plannable operation than complex repair.

If this strategy will be adopted for particular products, inventory management must be put in place to facilitate this, which comes with new considerations. Firstly, when in the process is the replacement part reserved for a particular customer to prevent stockout? And after replacement of a whole part, is the faulty part scrapped or repaired to add it to inventory? And are customers willing to accept refurbished parts as replacement? These are decisions that must be analyzed by TNNL when adopting this repair strategy.

Customer's service satisfaction

By standardizing and formalizing the information exchange during the process, they agree that the communication to the customer can be more frequent and in more detail. Improving the transparency and customer satisfaction.

For the repair lead time and on time delivery, the designed model can contribute to the structure and uniformity of the process flow, especially for the repair by replacement stream. However, the realization of a capacity planning and job routing is expected to have the most effect on the performance.

4.2.2 Expert opinion of CCC

The experts are a Chain manager and a Product manager of services. They are currently investigating and writing a communication plan on how to improve the internal and external information flow of the repair service. So especially the information logistics and its effect on the customer's service satisfaction can be validated in this meeting.

Repair lead time and On time delivery

From the perspective of the CCC, the custom repair by replacement process flow is useful to adopt, because the PCBA's are currently repaired before order placement of the customer, which goes against their conduct. They think that most customers are willing to pay a fixed price upfront if the lead times can be made shorter and less uncertain. Especially the master customers, which are customers characterized by forward planning and decent defensive budgets, because uncertainty of available resources is a risk for their extensively planned operations and military exercises.

When a more systematic process flow and capacity planning is realized at the engineer work cells, they think that the lead times are decreased and that more certainty about promise dates can be given. For repair by replacement, no order placement of the customer is required after inspection, this will also reduce the throughput time, because this can take over months if the customer does not have the urgency.

Information logistics

Concerning internal information logistics, they agree that the accessibility of status information can be improved by centralizing it in a single information system. The CP could be adopted by the Repair shop to log statuses of repairs but this will require coordination. Establishing a general terminology between all departments can help with bringing more structure in this task. However, this must be formulated and aligned with all involved parties, making it complicated. So this initiative was not taken yet.

Concerning external information logistics, they approve on the points in the process where standard updates are given to the customer, they also are working on something similar. The idea to communicate the planning of operations to the customer was not thought about yet, but it is a good addition.

The periodic updates to customers on an agreed interval are appropriate, but it is desired to cluster all services that a particular customer currently has in the pipeline at TNNL and communicate about the status of them all at once. This is more organized for both parties and it is more efficient than updating on individual repair cases. Also, Sales support tend to contact the Repair shop for updates on individual repair cases, disrupting the work activities of the Repair shop. These cases should be clustered too so that contact takes place on predetermined moments.

Also the application of the propositions of perceived waiting time from the theoretical framework was a subject that got their interest, this will probably be considered in their communication plan.

Customer's service satisfaction

By forming a standard internal information structure in the process, they agree that the external communication can be improved and standardized. It enables the CCC to communicate proactively to the customer and engage the customer more during the process. This gives the customers a feeling of clarity and improves the perception of the customer on the repair service.

5. EVALUATION

5.1 Conclusion

This research aims on answering the main research question:

What should the design of the repair service be to improve customer satisfaction?

The incentive to reshape the process of the repair service was to improve the customer's service satisfaction. From a customer survey, it came forward that the low satisfaction was caused by a lack of transparency on the state of the repair, and long unreliable lead times.

By forming a standard internal information structure in the process, the external communication to customers can be improved and standardized. Enabling TNNL to communicate more frequent and proactive to the customer, increasing customer's transparency on the repair process.

By creating a separate repair stream for replacements, shorter and more reliable lead times can be accomplished for these products. The process requires less work hours and administration, because inspection and repair activities are performed at once and are easier to execute. Therefore, there are more resources and work hours for the Repair shop and engineers to focus on the information logistics of the complex repair stream. In this repair stream, there are opportunities to give more operational transparency and to involve customers more in decision making during the process.

Furthermore the designed model can contribute to the structure and uniformity of the process flow, to increase the efficiency of the work process. Especially when a capacity planning and job routing is realized in the work cells. Improving the performance on the repair lead time and on time delivery.

In this way, the designed model contributes to resolving both causes of low customer satisfaction.

5.2 Recommendations and discussion

From the social and knowledge context arose improvement points that are not depicted in the designed model but are relevant to consider when implementing its process flow. Also during the model validation, attention points where identified that may form input for new research subjects.

Process standardization

For tasks and steps in the process that do not require an ad hoc approach, direct standards should be established, for instance through Standard operating procedures. For the CCC, this is already set up through the service desk process, but in the Repair shop no structured process is yet in place. It came forward in the literature that after inspection and determining the required repair jobs, the process flow could be more standardized to ensure compliance and coordinated planning. This also applies to information logistics in the repair process steps, where terminology is needed to make process information more understandable and unambiguous for all parties so that the information transfer is simplified. To design and establish standard procedures and an information terminology in detail, it is important to involve workers that have experience with the processes on a day-to-day basis. Furthermore, the capacity planning and job routing of the Repair shop and engineer work cells will contribute to the standardization of the process. The experts of the validation meeting of Chapter 4.2.1 are currently working on establishing this in the short term.

There are also processes surrounding the repair service that need to be set up for repair by replacement. For inventory management, a procedure is required to ensure that components or modules are in stock that follow this strategy.

After setting up standard procedures, they should be evaluated periodically to prevent the procedures from getting outdated or redundant. Also the process should be monitored continuously to make sure that the process participants follow the procedures properly.

When process standardization for information logistics is established in the internal organization, the next challenge is to engage suppliers in sustaining this information flow for external repairs.

Information systems

Currently, only a part of the customers has access to the Customer Portal, leading to a mixed form of contact with customers. If customers could be persuaded to adopt the use of the CP, the communication is organized in one place, instead of disordered mail or phone contact. For customers that do not want to adopt the CP, the internal CP could still be used to centralize and structure the status information of repair cases.

To have all this status information accessible in one place the proposed solution in the designed model is to let the Repair shop adopt the internal CP to share status updates with Sales support. In the expert opinion meeting with the Repair shop, the solution came forward to connect the ERP system with the CP, so that status logs in the ERP are automatically updated in the CP. It has the same effect and is easier to adopt for the Repair shop.

Product design phase

In the design phase of a product, logistic engineers determine if it is better to repair or replace its SRU's or components. This information is however not always consulted leading to inadequate repair decisions during the service phase. A close connection between the ILS and ISS phases is needed to choose the best service strategy for each system (Appendix B). When the new replacement stream is established, the factors in the repair or replace decision change, so for some systems reassessment is needed.

This connection also works the other way around, the knowledge and experiences from the service phase could also contribute to decisions in the design phase on how to make serviceable product designs. Currently most of the products are not designed to enable easy replacement of components or modules. So, if serviceability and modularization of the products are more considered during product design, replacement may be optimal for more products and a shift of repair stream percentages can emerge.

The repair by replacement strategy may lead to a simpler service provision, but it is not suitable for all inhouse repairs, since the high diversity, multiple versions, component obsolescence, and long life cycles of TNNL's products. It is not feasible and profitable to have all components in stock (Appendix A.4 & A.5.2). However, the adoption of more standardization and modularization in the design phase of products could reduce the number of unique components.

5.3 Further Research

This research contributed to the repair service by designing a standard for information logistics in the process flow and a custom process flow for repair by replacement. There are however more issues in the repair service that have to be determined further. Most of these issues have been discussed in detail at the discussion and recommendations of Chapter 5.2. Here it will be considered how academic research could contribute to these improvement projects.

Establishing capacity planning and routing of test and repair jobs will contribute to the standardization of the process flow. This currently is an improvement project of the Repair shop, but theory could help. It should be considered what planning strategy is fitting for service jobs and how this could be integrated with the ERP system. Also, using different planning strategies for the separate repair streams might be an option.

To fulfill customers' service expectations for external repairs, the contract agreements with suppliers must be aligned accordingly. Best cases of supplier relation management and contract management could help with streamlining the information logistics between TNNL and its key suppliers.

To facilitate the repair by replacement strategy, an inventory management procedure must be put in place. Research is needed to define a procedure and optimal parameters. Also, obsolescence management must be put in place to ensure the availability of these modules and components.

Lastly, the design of serviceable products could form an important long term strategy for TNNL. It should be examined how theories of modularization and standardization could be applied in the design phase of products.

REFERENCES

Berger, A. (1997). Continuous improvement and kaizen : standardization and organizational designs. *Integrated Manufacturing Systems*, *8*(2), 110–117. https://doi.org/10.1108/09576069710165792

Brax, S. (2005). A manufacturer becoming service provider - Challenges and a paradox. *Managing Service Quality*, *15*(2), 142–155. https://doi.org/10.1108/09604520510585334

Buell, R. W. (2019). Operational Transparency. *Harvard Business Review*. Retrieved from https://hbr.org/2019/03/operational-transparency

Davis, M. M., & Heineke, J. (1994). Customer Roles in Queue Management Understanding the Roles of the Customer and the Operation for Better Queue Management.

Dinter, B., & Winter, R. (2009). Information logistics strategy - Analysis of current practices and proposal of a framework. *Proceedings of the 42nd Annual Hawaii International Conference on System Sciences, HICSS*. https://doi.org/10.1109/HICSS.2009.253

Floyd, D., & Reyes, M. (2014). Application of the Integrated Product Support Elements by the F-35 Joint Program Office.

Gough, J., & Hamrell, M. (2009c). *Standard Operating Procedures (SOPs): How Companies Can Determine Which Documents They Must Put in Place*.

Gough, J., & Hamrell, M. (2009a). *Standard Operating Procedures (SOPs): How to Write Them to Be Effective Tools*.

Gough, J., & Hamrell, M. (2009b). *Standard Operating Procedures (SOPs): Why Companies Must Have Them, and*. Retrieved from www.diahome.org,

Gunasekaran, A., & Kobu, B. (2010). Modelling and analysis of business process reengineering. *Https://Doi.Org/10.1080/00207540210132733*, *40*(11), 2521–2546. https://doi.org/10.1080/00207540210132733

Harrington, H. J. (2006). *Process management excellence : the art of excelling in process management*. Paton Press LLC. Retrieved from https://books.google.com/books/about/Process_Management_Excellence.html?id=kvHO1PCQusAC

Heerkens, H., & Winden, A. van. (2012). *Geen probleem, een aanpak voor alle bedrijfskundige vragen en mysteries*. Van Winden Communicatie. Retrieved from https://research.utwente.nl/en/publications/geen-probleem-een-aanpak-voor-alle-bedrijfskundige-vragen-en-myst

Ho, D., Kumar, A., & Shiwakoti, N. (2016). Maturity model for supply chain collaboration: CMMI approach. *IEEE International Conference on Industrial Engineering and Engineering Management*, *2016–December*, 845–849. https://doi.org/10.1109/IEEM.2016.7797996

Ho, T., Kumar, A., & Shiwakoti, N. (2019). Supply chain collaboration and performance: an empirical study of maturity model. https://doi.org/10.1007/s42452-020-2468-y

Hong, J.-P., & Kim, B.-Y. (2020). The Perceived-experiential Value and Service Quality of Auto Maintenance and Repair Service. *Journal of Distribution Science*, *18*(1), 59–69. https://doi.org/10.15722/JDS.18.1.202001.59

Jones, P., & Peppiatt, E. (1996). Perceptions of waiting times in service queues Managing perceptions of waiting times in service queues.

Jones, J. V. (2006). Integrated logistics support handbook. Retrieved from https://books.google.com/books/about/Integrated_Logistics_Support_Handbook.html?id=XC3QkO-3lCYC

Klein, S. (1993). Information Logistics. Retrieved March 22, 2022, from https://www.semanticscholar.org/paper/Information-Logistics-Klein/8c50196fd8a690d10cf52a89dfc0b0d5d1f41d77

Looy, A. Van, Backer, M. De, & Poels, G. (2014). A conceptual framework and classification of capability areas for business process maturity. *Enterprise Information Systems*, *8*(2), 188–224. https://doi.org/10.1080/17517575.2012.688222

Lubis, M., Ananza, H. H. R., & Suryoputro, F. D. (2020). Analysis and Design of Policy and Standard Operating Procedure (SOP) for Information Technology in the Communication and Information Services Department. *6th International Conference on Interactive Digital Media, ICIDM 2020*. https://doi.org/10.1109/ICIDM51048.2020.9339659

Maister, D. H. (1985). The Psychology of Waiting Lines. Retrieved from www.davidmaister.com

Meier, H., & Massberg, W. (2004). Life cycle-based service design for innovative business models. *CIRP Annals - Manufacturing Technology*, *53*(1), 393–396. https://doi.org/10.1016/S0007-8506(07)60724-0

Michelberger, B. (2015). *Process-oriented information logistics: aligning process information with business processes*. Retrieved from https://oparu.uni-ulm.de/xmlui/handle/123456789/3272

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems* , *24*(3), 45–77. https://doi.org/10.2753/MIS0742-1222240302

Roza Albareta, A., & Mursanto, P. (2019). Design of Standard Operating Procedure for Requirement Engineering in Software Development: Case Study Data Processing Integration Subdirectorate Statistics Indonesia. *Journal of Physics: Conference Series*, *1175*(1), 012081. https://doi.org/10.1088/1742-6596/1175/1/012081

Shostack, G. L. (1984). Designing Services That Deliver. Retrieved May 17, 2022, from https://hbr.org/1984/01/designing-services-that-deliver

Wang, G., Wang, J., Ma, X., & Qiu, R. G. (2010). The effect of standardization and customization on service satisfaction. *Journal of Service Science*, *2*(1), 1–23. https://doi.org/10.1007/S12927-010-0001-3

Wieringa, R. J. (2014). Design science methodology for information systems and software engineering. *Design Science Methodology: For Information Systems and Software Engineering*, 1–332. https://doi.org/10.1007/978-3-662-43839-8

Zorzini, M., Corti, D., & Pozzetti, A. (2008). Due date (DD) quotation and capacity planning in make-to-order companies: Results from an empirical analysis. *International Journal of Production Economics*, *112*(2), 919–933. https://doi.org/10.1016/J.IJPE.2007.08.005